The California Desert Mineral Symposium

Compendium

United States Department of the Interior Bureau of Land Management

California State Office Sacramento, California

1989

United States Department of the Interior

BUREAU OF LAND MANAGEMENT
CALIFORNIA STATE OFFICE
2800 COTTAGE WAY, ROOM E-2845
SACRAMENTO, CALIFORNIA 95825-1889

IN REPLY REFER TO:

AUG 7 1989

Dear Reader:

Thank you for your participation in "The California Desert Mineral Symposium: Planning For Tomorrow." Your interest and concern surrounding the future role of minerals and their importance to society is essential for the promotion of sound decisions in the California Desert Conservation Area (CDCA).

The compendium that follows contains 38 papers representing the policy of multiple use and research associated with mineral exploration and development in the CDCA. This information has been generated by the scientific community, industry, and government in response to increasing interest in the California Desert mineral resources. Several critical topics addressed in these papers include:

- balancing the legal mandates associated with multiple use of the public lands, including management and protection of surface resource values, while providing for development of mineral resources with appropriate mitigation;

- enhancing public knowledge of, and appreciation for, the present and future importance of the California Desert as a major source of minerals needed for technological and scientific advances;

- defining the importance of Desert mineral production to local, State, national, and global economies;

- discussing new techniques and technologies for the discovery and recovery of minerals; and

- demonstrating state-of-the-art mining and reclamation techniques to mitigate mineral exploration and development impacts.

The issues are important to all Californians, and the implication of decisions we make about resources in the CDCA extend to all Americans. We thank all the people who prepared these papers for the symposium. They have provided us with truly significant knowledge and ideas on a complex challenge to today's society.

Sincerely,

Ed Hastey

Ed Hastey
State Director

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California Desert Mineral Symposium

Guest Speakers

Dr. Shirley Anderson, California State University, Northridge
T.S. Ary, Director, U.S. Bureau of Mines
Micheal Attaway, Bond Gold Colosseum Inc.
Kent Ausburn, Vanderbilt Gold Corporation
Dr. Carl Austin, China Lake Naval Weapons Center
Ed Barnum, Molycorp
Howard Brown, Pluess-Staufer, Inc.
Craig Byington, Homestake Mining Company
Marc Coolen, Billiton Minerals USA, Inc.
David Dellinger, U.S. Geological Survey
Mike Diggles, U.S. Geological Survey
Marion Ely, Mining and Reclamation Consultant
Mel Erskine, Mining Consultant
Daniel Eyde, GSA Resources, Inc.
Jim Fairchild, Kerr McGee Chemical Corporation
John Fitz-Gerald, Gold Fields Mining Corporation
Dr. Eric Frost, San Diego State University
Ron Geyer, Dupont, Co.
Tom Goerold, Wilderness Society
Scott Jenkins, Consulting Geologist
Dr. David Jessey, California Polytechnic University
Harold Linder, Mining Consultant
Dr. Michael McKibben, University of California, Riverside
Patty McLean, Bureau of Land Management
Curt McVee, Alaska Mining Association
James Moore, California Energy Company
Dr. Douglas O'Brien, Tessera Research Corporation
Terry Panhorst, Billiton Minerals USA, Inc.
Glenn Roquemore, Leighton & Associates
Ron Sheets, Virginia Polytechnic Institute
Gene Smith, U.S. Borax
Zane Smith, Former U.S. Forest Service Regional Forester
Charles Sorrell, U.S. Bureau of Mines
Dr. Donald Tarmen, California Polytechnic University
Edwin Tooker, U.S. Geological Survey
John Vandervoort, Poly-America Inc.
Johanna Wald, Natural Resources Defense Council
Stan Watowich, Gold Fields Mining Corporation

CALIFORNIA DESERT MINERAL SYMPOSIUM
MARRIOTT HOTEL, IRVINE, CALIFORNIA
PROGRAM SCHEDULE

- First Day -

Friday, March 3, 1989

7:30 a.m. Sign In and Walk In Registration Begins

	MAIN ROOM E	ROOM G/H	ROOM F
	Moderators - Gerald Hillier, District Manager, BLM-California Desert District. Joan Baldwin, President, South Coast Geological Society		
9:00 a.m.	Welcome by Gerald Hillier, District Manager, BLM-California Desert District		
9:10 a.m.	Welcome by Joan Baldwin, President, South Coast Geological Society.		
9:15 a.m.	Introduction of the Keynote Speaker by Ed Hastey. Keynote Speaker - Roland G. Robison, BLM Deputy Director, Washington, D.C.		
9:45 a.m.	Introduction of the Multiple Use Panel by Ed Hastey. Curtis McVee, Executive Director, Alaska Mining Association. -Multiple Use: A Challenge Zane G. Smith, Jr., Former California Regional Forester, U.S. Forest Service-Pacific Southwest Region. -A Renaissance of Multiple Use. Johanna Wald, Senior Attorney, Natural Resources Defense Council. -Multiple Use Concepts.		

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11:15 a.m.	Ron Geyer, Du Pont Company -An Overview of the Uses and Safe Handling of Cyanide in the Mining Industry.		
11:50 a.m.	-LUNCH- Luncheon Speaker - T.S. Ary, Director, U.S. Bureau of Mines. -Mineral Resources and Their Importance to Society.	-LUNCH-	-LUNCH-

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1:15 p.m.	David A. Dellinger, U.S. Geological Survey. -California's Unique Geological History and it's Role in Mineral Formation, with Emphasis on the Mineral Resources of the California Desert Region.	W. Thomas Goerold, Chief Economist - Energy and Mineral Resources, The Wilderness Society. -Mining and the California Desert.	Dr. Michael A. McKibben, and Dr. Wilfred A Elder, Department of Earth Sciences and Geothermal Resources Center, University of California at Riverside. -Modern and Ancient Geothermal Systems in the CA Desert.
1:45 p.m.	Stanley N. Watowich, Gold Fields Mining Corporation -Mineral Potential, Time and Economic Permissiveness.	W. Thomas Goerold, Chief Economist - Energy and Mineral Resources, The Wilderness Society. -Rare Earth Minerals, Superconductivity, and the California Desert.	Glenn R. Roquemore, Leighton and Associates. -An Interpretation of Microseismicity in the Coso Range, California.
2:15 p.m.	Dr. Carl F. Austin, Geothermal Program Office, China Lake Naval Weapons Center and James L. Moore, V.P. Exploration, Californ' . Energy Company Inc. -Overthrusting Models for the Southern Sierra and Adjacent Desert Region: A Key to New Economic Opportunities.	Dr. D.W. Tarman and Dr. David R. Jessey, Department of Geological Sciences, CA State Polytechic University at Pomona. -Relationship Between Extensional TecTonism and Silver-Barite Mineralization of the Calico Mining District, San Bernardino County, CA.	Mel C. Erskine, Consulting Geologist. -Regional Tectonic Setting and Geohydrology of the Indian Wells - Coso Hot Springs Area.

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2:45 p.m.	Dr. Douglas P. O'Brien, et. al., Tessera Research Corp-Tectonics of the Southern California Desert as Interpreted from Gravity and Magnetic Data.		Scott L. Jenkins, Geologist. -Geology, Alteration and Mineralization of the Blackwater Hydrothermal Cell, San Bernardino, County, CA.
3:15 p.m.	-BREAK-	-BREAK-	-BREAK-
3:40 p.m.	Dr. Eric G. Frost, California Consortium for Crustal Studies, Department of Geologic Sciences, San Diego State University, San Diego and Dr. Donna Martin Frost, Department of Geological Sciences, University of California at Santa Barbara. -Crustal Habitat of Precious Metal Mineralization within the Extended Terrane of Southern California and Western Arizona.	Dr. David R. Jessey and C. Nancy Fallis, Department of Geological Sciences, CA State Polytechic University at Pomona. -The Mohawk Mine: A Base Metal-Silver Deposit Related to Possible Late Cretaceous Normal - Slip Movement within the Clark Mountain Thrust Complex, San Bernardino County, CA.	Howard J. Brown, Pluess-Staufer, Inc. -Geology and Genesis of White, High Purity Limestone Deposits in the New York Mountains, San Bernardino County, CA.

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4:10 p.m.	Dr. Eric G. Frost, California Consortium for Crustal Studies, Department of Geologic Sciences, San Diego State University, San Diego and Stanley N. Watowich, Gold Fields Mining Corporation. -The Mesquite and Picacho Gold Mines: Epithermal Mineralization Localized within Tertiary Extensional Deformation.	J. Marc Coolen, Billiton Minerals USA Inc., and Allen C. Wattenburger, Earth Sciences Department, University of California Riverside. -Geology and Gold Mineralization at Blackhawk Mountain, San Bernardino County, CA.	Edwin W. Tooker, U.S.Geological Survey, and Larry D. Fellows, Director, Arizona Geological Survey and State Geologist. -A Discussion of the Poster: Industrial Rock and Mineral Resources of Arizona.

4:40 p.m. END OF SESSION

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Saturday, March 4, 1989

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8:30 a.m.	Welcome by Ed Hastey, BLM California State Director		
8:45 a.m.	Welcome by Joan Baldwin, President, South Coast Geological Society		
8:50 a.m.	Introduction of Keynote Speaker by Ed Hastey Keynote Speaker - Bill Leonard California State Senator		
9:30 a.m.	-BREAK-		
9:50 a.m.	Charles A. Sorrell, Office of Advanced Materials Coordination, U.S. Bureau of Mines - California Desert Minerals, Superconductors and Other Advanced Materials	Harold Linder, Consulting Geologist - The Castle Mountain Gold Deposit, Hart District, San Bernardino County, Calif.	Daniel T. Eyde and T.H. Eyde, GSA Resources, Inc. - The Hunter Mountain Wollastonite Deposit: An Immoveable Object Trapped by Irresponsible Forces
10:25 a.m.	Edmund C. Barnum, Manager, Technical Services, Molycorp Incorporated - Lanthology: Applications of Lanthanides and the Development of Molycorp's Mountain Pass Operations	Kent E. Ausburn, Vanderbilt Gold Corporation - Ore Petrogenesis at the Hart Gold District, Castle Mountains, San Bernardino County, California	Craig B. Byington, Alan D. Cox and Alan G. Wilcinski, Homestake Mining Company - The Ivanpah Project of the Mojave Gold Province - A Structural Approach

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11:00 a.m.	Gene Smith, U.S. Borax Corp. - An Overview of U.S. Borax's Operations in California and the Uses of Boron	Ronald Wynn Sheets, et al., Department of Geological Sciences, Virginia Polytechnic Institute and State University and Kent E. Ausburn, Vanderbilt Gold Corporation - Geology and Precious Metal Mineralization at the Morning Star Deposit, San Bernardino County, Calif.	Terry Panhorst, Billiton Minerals U.S.A., Inc. - Overview of the Standard Hill Gold Mine, Mojave, California
11:35 a.m.	-LUNCH-	-LUNCH-	-LUNCH-
1:10 p.m.	Dr. Shirley C. Anderson, School of Business Administration and Economics, California State University at Northridge - Mineral Resources of the California Desert and Their Significance to California's Economy	Dr. Carl F. Austin, Geothermal Program Officer, China Lake Naval Weapons Center, and Patty McLean, Associate District Manager, Bureau of Land Management, Albuquerque, New Mexico - The Coso Geothermal Development: An Exercise in Multiple Use	Marion F. Ely II, Mining and Reclamation Consultant. - Cyanide in the Environment.
2:00 p.m.	Jim Fairchild, Kerr McGee Chemical Corporation - Commercial Uses of Searles Lake Chemicals	Michael F. Diggles, Wilderness Program Coordinator, U.S. Geological Survey - Mineral Resource Assessments Under the Wilderness Program of the U.S. Geological Survey and the U.S. Bureau of Mines	John D. Vandervoort, Poly-America Incorporated - Geomembrane Uses in the Mining Industry
2:35 p.m.	John J. Fitz-Gerald, Assistant General Counsel-Operations Gold Fields Mining Corporation - An Overview of the Mesquite Mine	Marion F. Ely II, Mining and Reclamation Consultant - Natural Revegetation on Mined Lands	(NO OTHER SPEAKERS IN THIS ROOM)

Chapter 1

MULTIPLE USE

MULTIPLE USE: A CHALLENGE

Curtis McVee

Over the past two decades there has been an alarming trend in the concepts governing public land management. These concepts manifest primarily in the political arena and direct the development of policies for both state and federal public lands.

There has been movement away from scientific land management utilizing biological and physical data to manage land and resources. Decisions seem to be forced into the arena of the media, politics and emotion.

The prevailing pressure is to identify a use for each tract or area and have this use sanctioned through legislative or administrative action. The area is then designated under one of a multitude of land classification authorities and henceforth managed for the identified purpose to the exclusion of other uses.

While there are lands containing unique and unusual natural values which should never be jeopardized or risked by the impacts of other uses, it is a last resort and somewhat of an admission of failure that professional land managers, with over a century of scientific, technical development history behind them, cannot devise methods for continuing multiple use.

A decision to exclude uses of all but one principal group of resource users means we have accepted something less than an optimum contribution from our public land as a compromise or trade-off.

It is often said that because of experience, technology and training the mistakes of the past do not have to be repeated. This is true if we take advantage of this knowledge and don't let emotionalism dominate our decisions. Recognize that mistakes of the past were based on reasons, pressure to accomplish some goal or upon inadequate information and experience. Let's not fall victim to these same pressures, but use the knowledge accumulated by land and resource managers to make decisions based upon the capabilities of the land and natural resources.

This is truly protecting our resources' future productive potentials while simultaneously enjoying their benefits. There are vocal interest groups which attempt to gain the emotional and political edge through use of the media or other tactics. These groups should be recognized for what they are, one point of view or representation of one group of public land-users.

Multiple use allows for the maximum number of uses, yet recognizes that sometimes there are dominant values a caribou calving area or a rich mineralized area and other uses will be managed in recognition of these values. The risks are greater, but so are the rewards and it certainly requires knowledge, experience and skills in land and resource management and is much more challenging to evaluate all the resources, and design a plan considering all the values and the variables, thus benefiting several segments of our society.

Multiple use is not a popular concept, since user groups align with their specific resource or philosophical interest. The multiple-use manager will eventually have to make decisions adverse to each interest within the natural resource constituency.

We should demand that before any land designations or classifications are imposed on public lands that there is indeed a unique, unusual or dominant value which cannot be managed except by excluding all uses not related to the value identified. This analysis must include consideration of the resiliency and recovery potentials of the values at risk over time. We have a tendency to make decisions based on effects and impacts today, next week, or next year and not on projections 40-80 years hence.

Recently I read some appalling statistics concerning the scientific knowledge of people in the U.S..It is in this vulnerable environment that the professional land manager must present the complicated intricacies of land management to the public.

This burden falls on the land manager, the individual who absorbs the pressure from all factions. We must be convinced that professional land managers have exhausted modern technology, reached knowledge and experience limits to find solutions allowing simultaneous use of the land by the largest possible segment of the public. Discussion should not focus on either/ or, the designation of a dominant use, but should concentrate on the combinations providing the greatest contribution now and for future generations.

A RENAISSANCE OF MULTIPLE USE

Zane G. Smith, Jr., U.S. Forest Service, retired. Presently serving as American Forestry Association Pacific Representative, Springfield, OR.

In the mid 1980's two bus loads of Bavarian foresters toured the Pacific coastal States viewing public and private land natural resource management. Professor Richard Plochmann, University of Munich's Forestry Chair, observed, "this is not multiple use". Dick was the German guide and interpreter reacting to the U.S. hosts claim of multiple use management for the activities on the tour. The comparison with the German and European model is stark. Their first impression was of the scale of activity and the apparent lack of integration of other used or activities. It met their definition of single use on a massive scale more, and often adjacent to other single use or set aside on an equally large scale. They all wondered aloud why the Americans didn't practice multiple use management on an integrated, smaller scale and thus greatly increase the total benefits from our land and resources.

A few months ago while I headed up the new U.S. Forest Service Recreation Strategy development, I talked to many people about a renewal of National Forest recreation within the context of multiple use. Dave Talbot, Director of Oregon's Recreation and Parks, summed up the reactions pretty well when he said, "multiple use is dead".

Upon reflection I think it may not be multiple use, the concept, that suffers from lack of support. It may rather be its application as evidenced by public land agency actions and the extreme view of what advocate groups want it to be. A look at the circumstances surrounding multiple use today may be useful as we think about its future.

THE SITUATION

There can be little doubt that there has been a confidence loss in multiple use. Even multiple use agencies such as the Forest Service and the Bureau of Land Management find themselves avoiding the term. Individual employees advocate different labels and approaches. We have given the public the impression that it is unworkable and the debate over a proper balance has too often got hopelessly bogged down. Few believe multiple use will serve their particular interests after all the negotiations are complete.

There have been some mighty changes in our population. As a nation we ar now 75% urban. California is 95% urban and continuing the trend. Much of this large urban population has lost its connection with the land and the resources that sustain life. Three and four generations in our Los Angeles Basin have no idea of their relationship with the land. They understand very little about what is required to provide the water, energy and materials that support their existence anu staiuards of living. They are ill equipped to participate in natural resource decisions and priority setting. They appreciate beauty and naturalness but equate resource use as destructive. They are easily influenced by extreme views when given part of the story.
This same population is, per capita, the heaviest consumers of natural resources in the world. They waste more than most people in the world have for their disposal. Nowhere is this more evident that in our bellwether State of California. We have become a "me society" with little willingness to accept the preferences of others. This has led us to exploit the resources of other countries particularly the undeveloped Third World. Growing dissatisfaction among Third World peoples promises to alter this reliance.

Natural resource decisions are more and more being made by the courts, lawyers and the legislative branch of government. Their role in policy making, of course, is unquestioned. The detailed resource evaluations and prescriptions to achieve land use objectives should involve professionally trained people, however. Natural resource managers have been taken out of the decision making loop and at the cost of greatly reduced benefits of all kinds.

Where balanced and publicly accepted multiple use plans are in place, our political leadership has failed to invest in the resources of people and dollars to implement them. The California Desert Plan is a good example of a government/citizen effort that the agency is left to implement without adequate investment. The advantages and increased benefits from multiple use cannot be realized without investment. The concept should not be blamed as unsuitable as a guise to limit certain uses.

Legislation at the Federal and State levels for these and other reasons has not supported multiple use. Political frustration over natural resource problems and the trade-offs inherent in multiple use planning has led to a deluge of single use laws affecting our public lands. These single use designations have been supplemented with detailed management prescriptions for the professional agencies.

All this has created a situation of reduced productivity for our natural resource land base and shifted our reliance to foreign countries. The trend is frightening when one looks at the increasing population, upward demand and deteriorating environment.

THE FUTURE

The future calls for a "renaissance of multiple use". Not as we have viewed multiple use in recent years but as the term "renaissance" implies- a rebirth, a revival! I would like to offer a five point program that would represent a renaissance.

First lets insist that our legislators focus on productivity and sustainability of natural resources as our conservation agenda. We perhaps will never be through preserving and protecting our sensitive environment and special places. But we have taken care of the "crown jewels" and most of the places that deserve preservation. In the future we simply can't point to a system of preservation and expect to sustain a decent life for the generations that follow. Encourage the legislators, court, and lawyers to concentrate on policy and overall purpose, leaving the prescriptions to the professional agencies. Make both groups accountable to the people.

Secondly, embark on an intense public education effort begins with school children and going right on up to our growing aged population. Promote an understanding of mankind's relationship to the environment we live in. An informed public will create a political environment that values sustainable use. An educated public will become involved in local decisions affecting natural resources. As they better understand their own relationship to land and resources they will become more tolerant of co-existing uses that respond to the preferences of our diverse population.

Third, we must invest in the leadership and the resources necessary to make multiple use work. Professionally designed plans prepared with the assistance of the public and ultimately with their concurrence must be funded. Durable and balanced multiple use requires investment, but probably less than the alternatives.

Fourth, as a nation we must move toward self sufficiency. We cannot morally expect nor reasonably rely on the Third World countries to supply our natural resource needs. They will not forever permit exploitation of their energy, mineral and fiber reserves to satisfy our appetite for lavish living.

Lastly, lets insist that our managing agencies like BLM and Forest Service scale down their application of multiple use. We cannot expect all uses on every acre but we can look forward to a better integration of uses on smaller tracts of land. Multiple use doesn't have to mean trade offs all the time. Lets consider the enhancement opportunities that multiple use can offer if we take the time to design activities with that in mind. In doing this we need to acknowledge special "places". I think too often we as resource managers do not have a sense of place. Frequently large blocks of land are given a broad purpose and prescription without recognizing small but special places within them that deserve to be handled differently. It might be a small canyon in a desert environment, a spring or special fishing hole or a scenic vista. Many of the stalemates growing out of controversy could be avoided if these special places were given the treatment they deserve.

You can see that I am unwilling to abandon the principle of multiple use. A close examination reveals there is no better approach to realizing the greatest benefits over the long term. An associate of mine recently said, "pursue it with a full court press". I believe we can with a RENAISSANCE OF MULTIPLE USE.

Chapter 2

GENERAL GEOLOGY AND MINERAL POTENTIAL ECONOMICS OF CALIFORMIA DESERT

MINERAL RESOURCES OF THE CALIFORNIA DESERT AND THEIR SIGNIFICANCE TO CALIFORNIA'S ECONOMY[1]

SHIRLEY C. ANDERSON School of Business Administration & Economics,
California State University, Northridge, CA 91330

Abstract

The California desert is one of the most important mineral repositories in the world. Currently over $1.3 billion of minerals are produced from the desert annually, from over 25 different minerals. The importance of desert minerals to California's economy is demonstrated by descriptions of the current uses and trends in cement, boron, rare-earth minerals, saline minerals, gypsum and gold.

The California desert mining industry directly employs 16,640 people in the five-county area of Imperial, Inyo, Kern, Riverside and San Bernardino. It employs 19,630 people in Southern California.

Mining jobs affect the region directly and indirectly. Direct effects include providing mining wages, mining equipment, sales, transportation and other services sold to the mining industry. Indirect effects include wages and salaries in industries in which mining products are used to manufacture other goods and services.

Each $1 million in mineral production (current desert production is $1.3 billion) directly accounts for 12.8 jobs in the five-county area; 15.1 jobs in the greater Southern California region.

Value added, which reflects direct effects on regional employment and the production of materials, equipment, and services supported by that employment, accounts for $754,799 per $1 million production in the five-county region ($981.2 million total) and $898,422 per $1 million production in the Southern California area ($1.1 billion total).

Within the five-county region, every $1 million of minerals production annually accounts for $26,439.04 ($34.3 million total) in local taxes and $41,877.18 ($54.4 million total) in state taxes.

For the greater Southern California region, each $1 million in production accounts for $28,854.39 ($37.5 million total) in local taxes and $47,182.85 ($61.3 million total) in state taxes. precluding resource development from this mineral rich area, as would occur under the California Desert Protection Act, is not necessary. Mining companies are able to meet and exceed stringent environmental regulations in order to produce materials needed by our society, while providing a strong economic base to the desert region.

Introduction

Recent legislation, The California Desert Protection Act(CDPA), sponsored by Senator Alan Cranston and Representative Mel Levine would, if passed, have a profound impact upon land use in the California desert, an area representing 25 million acres (approximately 40,000 square miles) and about one fourth of the State of California. It would have a major impact upon how the desert is used, and severely affect access into the region for recreationists, ranchers, hunters, miners, and the military.

Under the bill, the land use pattern within the desert (Appendix 4) would be distributed as shown in Table 1.

TABLE 1
CDPA PROPOSED DESERT LAND USE

1. Parks and Wilderness (no commercial activity)	10,400,000 acres
2. Military Bases (no public access)	3,100,000 acres
3. Other(Private, state & other federal holdings with limited or no public use)	7,400,000 acres
Subtotal (no commercial activity)	20,900,000 acres
4. Public lands open to restricted, moderate and intensive use	4.100,000 acres
Total	25,000,000 acres

1Data for this report were gathered during the later half of 1987.

The author gratefully acknowledges the assistance of the members of the California Mining Association in providing the desert mining data base necessary for this study. Also the information contributed by many geologists, in particular staff members of the California Division of Mines and Geology, is greatly appreciated.

As noted in Table 1 and shown in Figure 1, only 4.1 million acres, or 16.4 percent of the desert area would be left open to general public use, other than for wilderness or park uses and military operations. It appears obvious the affects of the CDPA would be profound and far-reaching, not only to Californians but to the nation as a whole. It is the intent of this paper to focus on the effects the Act would have upon California's mineral productive ability and its consequences upon our society.

CDPA PROPOSED DESERT LAND USE, PERCENTAGES

Million Acres				Percent
4.1	Public Lands: Open to Restricted to Intensive Use		Open to General Public Use (Mining)	16.4
20.9	7.4	Other	Private & Govt. Holdings with limited Or No Public Use	29.6
	3.1	Military	No Public Access	12.4
	10.4	Parks and Wilderness	No Commercial Activity	41.6

Figure 1.

Overview of Desert Mineral Resources

The California desert represents one of the most important mineral repositories in the world. At least 40 different mineral products have been produced in the past from the area, and no less than 25 distinct mineral commodities valued at over $1.3 billion have been produced from there in 1988. Some of these, namely the boron minerals and rare-earth elements serve a global market and hence are of world-wide importance. Products such as cement, clay and stone produced from the desert play a direct role in the economy of Southern California. They are especially vital to the construction industry because their delivered price to the construction site is largely dependent upon haulage distances from the mine. Other commodities such as pumice, gypsum and the various magnesium, potassium and sodium bearing minerals, are of great importance to other segments of the California economy such as agriculture, manufacturing, building and fabricating industries.

Changing technology, shifts in demands for specific mineral commodities, and commodity pricing all play a role in what minerals are produced from the desert. As a consequence, mineral resource production is both dynamic and responsive to events as they take place at the local, national and international level.

To illustrate the varied role of desert mineral Production we will examine a few of these minerals to provide insights into their importance.

Cement

In 1986 California produced 9.8 million tons of cement valued at $622.9 million (Burnett 1987). Approximately 70 percent of this production, with an estimated value of $436 million, represented cement produced from the western margin of the desert. Production and processing sites are located west of Mojave in Kern County, in Lucerne Valley and Victorville in San Bernardino County, and in western Riverside County, near Colton. About seven million tons of cement are produced in a typical year from these locales. A major part of it is used in Southern California where it goes into construction of buildings, homes, highways and a host of other infrastructure needs. Table 2 shows that California cement production has grown with California population, although affected also by economic variables such as the interest rate and government construction spending.

Historical data show the national annual consumption of cement is about 710 pounds per person. In California this figure is slightly higher, amounting to approximately 720 pounds per capita.

TABLE 2
CALIFORNIA POPULATION & CEMENT PRODUCTION GROWTH, 1976-86

Year	Population(in 1,000's)	Cement Production(1000 short tons)
1976	21,653*	7,896**
1977	22,075	9,271
1978	22,566	8,989
1979	22,991	9,724
1980	23,509	8,797
1981	23,991	8,302
1982	24,495	6,464
1983	25,021	7,567
1984	25,482	8,715
1985	26,055	9,462
1986	26,675	9,800

* Fay, J.S., et al, 1987
**California Geology, 1977-1987

Cement produced in California is very competitive with that shipped in from outside the United States, notwithstanding the fact major cement production occurs within a hundred miles of the greater Los Angeles area, where over 50 percent of California's population reside. Given the fact that in recent years cement has sold for about $50 per ton, if an additional 100 mile haulage is added, it would increase the delivered cost $7.00 per ton, based upon a 7 cents per ton mile haulage cost. Thus it is clear that haulage cost has an important impact on the delivered cost of cement and hence represents a major factor in determining a producer's ability to compete with foreign sources.

In recent years there have been two disturbing trends that affect the U.S. cement industry, namely a sharp increase in foreignownership of U.S. operations and a measurable increase of importation of cement materials into the United States. California, being a coastal state, has felt the full impact of these trends. A glance at label 3 below gives an idea of how pervasively importation has penetrated the U.S. cement market. If this trend of foreign entry into the domestic market continues, we can expect to see profits from domestic operations dwindle and the possibility later of foreign cartels forming and driving the price of cement upward. this would have a severe impact upon the costs of housing, construction of public works, and result in higher taxation to pay for public facilities that are built and an increase in cost of new home construction. It is difficult to determine the total effect this would have on workers and truck drivers who are involved in cement production and delivery. However, it is safe to assume it would have a measurably negative impact. In the desert area, it is estimated approximately 750 people earn their livelihood directly from cement production, and 400 more are employed in transportation of this material.

TABLE 3
U.S. CEMENT EXPORTS, IMPORTS & CONSUMPTION(1OOO short tons)
Data Source: U.S. Bureau of Mines, 1988.

Year	Production	Imports	Exports	Apparent Consumption*
1983	70,420	4,721	118	73,435
1984	77,700	8,689	80	84,113
1985	77,895	14,120	98	87,456
1986	78,786	16,128	59	91,501
1987	78,300	18,000	60	93,000

*U.S. Apparent Cement Consumption = Domestic production plus imports minus exports plus adjustment for industry and government stocks.

Boron

California is the world's leading producer of boron minerals. Over 650,000 tons of boron oxide (8203) is produced yearly in California, valued at $430 million. Production sites are located near the town of Boron in eastern Kern County, at Searles Lake near Trona, and in the Death Valley area in Inyo County. The biggest industrial user is the glass industry, especially production of fiber glass. Other major uses include such diverse activities as metallurgical applications, fertilizers, herbicides, detergents, cosmetics, manufacturing of aircraft and automobiles, along with a myriad of other uses.

It is estimated about 10 percent 165'000 tons) of boron oxide-bearing material produced in the desert is consumed in California and 40 percent (260,000 tons) in the United States, with the remaining 50 percent (325,000 tons) entering the world market. The only major competing boron production comes from Turkey with which U.S. producers compete on the world market. The boron industry in California provides direct employment for about 2000 people at mining and processing plants in the desert, and at shipping facilities in the Los Angeles harbor area.

There are other known boron deposits in the California desert of probable commercial value which could be brought into production. However, if the CDPA were to be enacted it is likely these deposits would no longer be a supply source of boron minerals.

Rare-Earth Minerals

Rare-earth (lanthanide) mineral production is a comparative "new comer" to the California mining scene, having only started a few years after the close of World War II. A "world class" rare-earth metal deposit is located at the Mountain pass area near the Nevada border. Elsewhere in the desert, other rare-earth element deposits are known. These locales are situated in areas slated for National park and Wilderness status under the CDPA.

Production from the Mountain Pass deposit during 1987 yielded 18,000 tons of bastnasite, the host mineral for the rare-earth elements. Bastnasite was separated into concentrates and hi-purity compounds including cerium, lanthanum, yttrium, europium, samarium, neodymium and gadolinium valued at around sixty million dollars in 1987. The material produced serves a global market where it is employed in a wide variety of applications which include surgery, communications, cutting organic and ceramic materials, fiber optics, photography, and space exploration.

The recent development of super-conducting materials for transmission of electric power and very high intensive strength "super-magnets" have resulted in a global interest in rare-earth elements. Because of the great promise such products have in reducing energy losses in transmission of power, and in being able to downsize equipment that uses magnets, there is potentially an explosive demand for the rare-earth elements that could well result in new "high technology" companies locating in California.

Saline Minerals

The saline minerals are produced from dry lake areas situated in the desert. They include calcium chloride, magnesium compounds, potassium salts, sodium carbonate and sodium sulfate with an annual production valued at several 10's of million of dollars.

Major uses of the saline mineral products include manufacturing of glass, rayon, soap, detergents, as a fertilizer ingredient and for water treatment.

Searles Lake, situated near the town of Trona in Inyo County, is the major source of saline minerals produced in California. Elsewhere in the desert similar deposits are known to occur in other dry lake areas, some of which have yielded production in past years. Passage of the CDPA would likely preclude some of these from becoming productive.

Over 1000 people in California are directly dependent upon production of saline mineral products for their livelihood. In addition, an undetermined number of truck drivers and railroad employees are involved in transporting the materials to the market place.

Gypsum

California is the second largest producer of gypsum in the United States. By far the bulk of California production comes from the desert. Elsewhere in the desert there are known large deposits of gypsum that are not in production at this time. Passage of the CDPA would preclude mining of these

deposits. Gypsum is used as unemployment of 7,700 was 19 percent of the county labor force-the highest unemployment rate of any county in California!

A number of new gold deposits in the desert area are being planned for production. One of particular note is the Castle Mountain deposit located in eastern San Bernadino County. It is considered a "world class" gold deposit in which about two million ounces of gold have been established, and this figure is expected to increase with continued exploration drilling on the property. Annual production of 100,000 ounces of gold is Planned, which would be valued at about $40 million dollars at the current price of gold. (t is anticipated that this mine would require about one hundred employees. The deposit is situated within the East Mojave National Park proposed by the CDPA, and as a consequence it is problematic whether it could be brought into production if the CDPA were enacted.

Based upon the favorable geologic environment for occurrence of significant gold deposits in the California desert, it is anticipated that at least 75,000 ounces of new gold output each year will be added to production from the desert over the forthcoming decade provided the desert area as it is known today remains open to mineral entry. In conclusion, gold production from the desert represents a major growth industry and the benefits from this activity will extend throughout the state in general, and especially in Southern California, provided there are no legislative mandates to curtail exploration and development of this mineral resource.

INTRODUCTION TO THE STATISTICAL ANALYSIS (BY RSRI) OF THE DIRECT AND INDIRECT ECONOMIC IMPACTS OF THE CDPA

Background to Analysis

There is much published geological and mines data indicating the importance of California desert production. However, an exact measure of the value of desert employment, output, wages, tax revenues and value added by desert production required that data be collected from the desert producers. Further, an analysis of the economic impact that desert mining cutbacks, forced by the CDPA, would have on local counties and on Southern California required an economic input-output analysis.

In June 1987, members of the California Mining Association agreed to submit data pertaining to their own company's desert mining operations. (See Appendix 1 for questions asked.) For antitrust and marketing reasons, the members of the mining association agreed to send their data individually to a non-industry academic (the author of this study), who would total the variables so that sensitive individual company data would not be revealed to competitors. The company data were collected during the following two months for tabulation and further processing by input-output analysis. The response of completed questionnaires represented 80 percent of the total dollar value of desert area mining production, which was deemed adequate for the study.

The Regional Science Research Institute (RSRI) in Rhode Island, a non-profit institute directed by Dr. Ben Stevens, publisher of the Journal of Regional Science, was chosen to perform the input-output modeling and data analysis(see Appendix 6).

Data totals were sent to RSRI for statistical analysis of the total impacts of desert mining cutbacks on the Southern California economy, and on the 5-county local economy. RSRI used the survey data (plus a 20 percent factor to cover the 20 percent of known production from companies who did not respond to the questionnaire) as input to the RSRI input-output model of the Southern California economy. The results are shown as Appendix 2. RSRI also estimated a 5-county input-output model (consisting of Imperial, Inyo, Kern, Riverside and San Bernardino counties), which modeled the 5-county economy local to the desert mining activity. see Appendix 3 for results. Economic Modeling by I-O Analysis.

In general, an input-output (I-O) analysis is based on the fact that industries are interconnected, dependent upon each other as suppliers and as customers.
The economic impacts of desert mining cutbacks which are considered in the I-O analysis include the direct effects on regional employment and the production of materials, equipment and services as inputs to desert mining. They also include indirect and induced effects which are, respectively:

- The loss of jobs and production that had been required to support former levels of direct employment, now lost through the desert mining cutbacks, (e.g., loss of demand to businesses that indirectly supply the mining industry),
- And the lost jobs and production formerly required to

fulfill the household demands for goods and services generated by the former wages of employees who have lost their jobs because of the CDPA (e.g., loss of consumption demand by households of grocery store clerks who become unemployed because of t:he CDPA).

The Indirect effects can be viewed as a set of ripples in the economy, since indirect, like direct, outputs require material and service inputs for their production, and so on. The loss in induced household expenditures generates further ripples of losses in expenditures. The total of direct, indirect and induced output effects per dollar of mining industry output cutback may be termed the desert mining output multiplier.

The mining industry is at the base of manufacturing of most components and finished industrial and consumer products and services. Mining output is a basic input, on which is generated value added in the production of many goods and services. Therefore, loss of a mining job affects both direct recipients of mining wages, mining equipment sales, transportation and other services sold to the mining industry, and also indirectly affects wages and salaries in industries in which mining products figure as inputs in the manufacture of other goods and services. A regional I-O analysis of the total impacts of desert mining cutbacks would include only the impacts that do not leave the region. "Exports" to other states would, of course, also have direct and indirect impacts on those states, that are not reflected in the current analysis.

Results of the I-O Analysis

Appendix 2 lists output, employment, wages and value added multipliers for the Southern California economy. Appendix 3 does the same for the 5-county region encompassing the desert. Table 4 below shows selected results for both the Southern California economy and the five-county economy local to the desert. It can be seen that the economic impact of cutbacks in desert mining cutbacks is predominantly on the five-county economy. These are long term effects of the CDPA (i.e., little or no mining in the desert).

TABLE 4
I-O RESULTS: TOTAL EFFECTS & MULTIPLIERS

	Employment1	Output2	Wages2	Value Added2
Southern CA Economy				
Total Effects	-20,353.9	-2378.397	-450.572	-1209.713
Multipliers	2.669	1.766	2.339	1.504
5-County Economy				
Total Effects	-17,276.3	-1936.950	-364.240	-1016.326
Multipliers	2.666	1.439	1.891	1.504

*Appendix II, p1.
**Appendix III, p.1. The five counties are Imperial, Inyo, Kern, Riverside and San Bernardino.
1Employment is in jobs.
2Dollar figures are in millions."Value Added" equals output revenue minus the costs of materials, supplies, energy and contract work. Value added includes labor expense, administrative and sales costs and operating profits.

Page 1 of Appendices 11 and 111 list employment, output, wages and value added effects of the loss of desert mining on each of the major sectors of the Southern California economy and the five-county economy, respectively. For example, loss of desert mining implies a loss of 2,276 jobs in Transportation and Public Utilities, and a loss of 20,354 total jobs in all sectors for Southern California.

The loss of one desert mining job implies a multiplied loss of 2.669 total jobs in Southern California (Table 4 and Appendix II, p.l). The output multiplier for Southern California is 1.766, meaning that every dollar of desert mining output lost results in a total loss of $1.76 in demand for Southern California economic output. This is based on the conservative estimate of $1,346,485,000 of 1987 desert outpu' (Appendices 11 & 111, p.1, the "total initial disturbance").

Loss of desert mining also implies lost state and local taxes of $63,531,000 and $38,852,000 respectively (Table 4 & Appendix II, p.1).

The RSRI model categorizes the major economic sectors into 82 subsectors (Appendices 11 & 111, pgs. 2,3), with a listing for each subsector of the employment, output, wages and value added impacts of loss of desert mining on the Southern California economy. Although impact of a desert mining cutback is felt in almost every sector of the economy, the transport, retail trade and services sectors are particularly hard hit.

The employment impacts of the loss of desert mining can also be displayed by occupational category rather than by industry (Appendices 11 & 111, pgs. 4,5). Managers, clerical workers, craftsmen, transport and non-transport operatives and personal service workers are the occupational categories most impacted by a decrease in desert mining.

Table 5 shows the effects of mining cuts per million dollars of lost mining output. The impacts per one million dollars are obtained by dividing the "total value added of desert mining" by the total value of "desert mining output." for example, the total Southern California loss of value added (if desert mining is shut down) is $1,209,719,000. The value added loss per one million dollars decrease in desert mining output is $898,422, which is $1,000,000 times $1.209,719,000 divided by the $1,346,485,000 dollars of direct desert mining output currently faced with extinction by the CDPA.

TABLE 5
I-O ANALYSIS RESULTS: EFFECTS PER MILLION DOLLARS OF CUTBACK IN DESERT MININC PRODUCTION

Economic Impact	Southern California Economy*	Five-county Economy**
Employment	15.1 jobs	12.8 jobs
Income	$334,628.40	$270,511.90
State Taxes	$47,182.85	$41,877.18
Local Taxes	$28,854.39	$26,439.04
Value Added	$898,422.74	$754,799.20

*Appendix II, p1
**Appendix III, p.1.

1. A loss of 12.8 jobs in Imperial, Inyo, Kern, Riverside and San Bernardino counties;a loss of 15.1 jobs in Southern California.

Some effects of a one million dollar cutback in desert mining on the five-county economy local to the desert and on the Southern California economy (Table 5 and Appendices II & III: p. 1) will be the following:

1. A loss of 12.8 jobs in Imperial, Inyo, Kern, Riverside and San Bernardino counties; a loss of 15.1 jobs in Southern California.
2. A loss of $26,439 in local taxes in the 5-county area; loss of $28,854 in Southern California.
3. A loss of $754,799 in value added in the 5-county area; loss of $898,422 in Southern California.

The I-O analysis can be broken into direct and indirect and induced impacts. For example, the total effect of cessation of all desert mining (as of 1988) would be a direct decrease of annual output of $1,346,485,000. In addition, there would be an indirect and induced effect on the economy of about 75 percent (multiplier = 1.766) of the size of the direct effect. The total (direct plus indirect and induced) effect would be a permanent $2,378,397,000 decrease in the Southern California's annual economy. Of the $2,378,397,000 of output which is sacrificed if 100 percent of desert mining is shut down, any smaller impacts can be simply calculated as a percentage of the total number.

Any part of the total effect of a mining shutdown can, alternatively, be calculated from the output multiplier of 1.766 (Table 4). Based on a study of the mining company data, less than a 30-year life is expected for a substantial amount of the desert mining operations. Most of the current mining reserves would be gone in 50 years. Assuming that with the CDPA exploration was curtailed, the current desert mines would, on average, be largely depleted over the next 50 years. From this estimate we can extrapolate a 2 percent annual rate of mine shutdowns, given the restrictions of the CDPA. Then the annual direct loss of output to Southern California would be $26,929,700 (2 percent of

$1,346,485,000) and the total (direct plus indirect and induced) annual loss of output would be 1.766 times that figure, or $47,557,850.

The 2 percent annual mine depletion scenario is a generalization and does not take into account the rapid growth in demand and production of some of the desert minerals. That is, the economic impacts and losses to local and Southern California economies listed below (and in the Appendices) neglect the current, and expected future, dynamic growth in demand.

As two examples of growth factors that should be included in assessing desert mineral economic impacts, consider cement and gold:

Cement demand growth parallels that of population growth, which is projected for Southern California at about 2 percent per annum. Assuming 2 percent annual growth in desert cement production (in the absence of the CDPA), the estimates presented here of the annual impact of the cement mining industry on the Southern California economy in 5 years would understate the true loss by more than ten percent.

In general, demand for most of the minerals mined in the California desert grows at or greater than the population growth rate. Therefore, using 2 percent as a compound rate, the mining industry in 5 years will be worth $1.486,628,000 rather than the current (1987) $1,346,485,000 in direct output value. In 10 years, it would be worth $1,641,357,700 and in 30 years worth $2,438,971,200 to the Southern California economy in direct impact.

Gold demand is global and fast growing, as expanding high-tech and military uses compete with traditional monetary demand for gold. In the past 6 years desert production has increased over two thousand percent and is expected to increase by approximately 75,000 ounces, or 29 percent, per annum. Currently desert gold production annually adds $117,000,000 to the Southern California economy. Given the forecast 75,000 ounces annual production increase, in 5 years the increased California desert Production will total 635,000 ounces, or $254,000,000 (at the current price range of $400 Per ounce).

In summary, the economic impacts and losses to local and Southern California economies listed in this paper are conservative, neglecting the dynamic growth in demand that is expected by industry experts.

EFFECTS OF THE CALIFORNIA DESERT PROTECTION ACT

Positive Effects.

1. It would create vast areas of wilderness and parks for the aesthetic enjoyment of society and future generations.
2. It would protect desert ecosystems.

Negative Effects. -short Run and Intermediate Term.

1. An immediate effect would be a sharp decline in mineral exploration with attendant loss of local employment. Many of those who work in exploration, or at service industries such as motels restaurants, and other businesses which support exploration would lose their jobs. In some cases these losses could become so severe that local business failures would follow. In this eventuality we would expect to see a measurable negative impact upon local tax revenues and decline in taxes at both the state and federal level as well.
2. As mines become depleted, which would begin shortly after the enactment of the CDPA, all of the above effects would be accelerated. Local users of mineral products in the Los Angeles area and the rest of Southern California would experience price increases for those materials that are no longer produced in the desert.
3. For every million dollars of desert area mining lost, the direct and indirect impacts on the Southern California economy are as follows (Table 5):
   a. Loss of 15.1 jobs
   b. Loss of $334,628 in annual personal income
   c. Loss of $47,180 in annual state tax revenue
   d. Loss of $28,800 in annual local tax revenue

To illustrate these losses, let us assume mining output declined at a rate of 2 percent per annum. In 5 years this would represent a 10 percent sustained decline in output which would amount to $130 million dollars. the permanent consequences of the annual 2 percent decline in five years after the CDPA takes effect, would be as follows:

a) loss of over 1900 jobs,
b) loss of $43.5 million in annual personal income,
c) loss of $6.1 million in annual state tax revenue,
d) loss of $3.7 million in annual local tax revenue.

Thus it is clear that in just five years the negative impact upon jobs, personal income and tax revenues would be substantial. These shortfalls would have to be picked up by other segments of the economy in order to maintain the pre-CDPA level of employment and standard of living.

Negative Effects. -Long Term.

In the long term, most mining will have stopped because of depletion of reserves in areas not affected by the CDPA. Prices of commodities that are transportation sensitive would experience substantial increases because of greater haulage distance. The following permanent impacts on the Southern California economy (Table 4) would be sustained:

1. Loss of 20,354 jobs, of which 17,276 would be in the 5-county desert area.
2. Loss of $2 billion in annual Southern California production output of goods and services, including loss of direct, indirect and induced output.
3. Loss of $450 million in annual wages.
4. Loss of $1.2 billion in annual value added. 5. loss to the State of California of $63.5 million in annual state tax revenue.
6. Loss to the Southern California municipalities of $38.8 million in annual local tax revenue.

Major Problems.

1. Over the next 25 years, there is predicted to be an increase of 7,000,000 inhabitants in Southern California, which will require a large increase in construction material. This will accelerate depletion of cement, gypsum, clays and other earth materials used in construction. Where is this material to come from, if it doesn't come from the desert? How much will this add to the cost of new construction and home ownership, and how will this affect affordable housing for low income households?
2. If desert mining is curtailed, then in order to supply raw material needs, mining must take place elsewhere. The larger haulage distance to bring the mineral resources into their California market represents a wasteful use of scarce energy resources, adds to pollution, and increases public safety problems. How will the loss of energy resources from excess haulages brought about by the CDPA be replaced?
3. Mining elsewhere would almost surely occur where environmental safeguards are less stringent than in California, or virtually non-existent as in some developing countries. Thus in the larger picture we see a net degradation of the environment. Would it not be better to have these operations in California where we would have the benefit of seeing that they are conducted in an environmentally acceptable fashion, were 8,520 timber jobs but only 5.000 today. He went on to mention that the county may lose another 1,852 jobs if recently denied timber-harvest permits are not ultimately granted. Is this the scenario we can expect for desert residents if the CDPA is enacted? Those who live in the cities that service the mining industry can also expect to pay the price of unemployment. This would include service companies, truck drivers, warehousemen, dock workers, salesmen and an almost endless list of other occupations that will be affected. In addition they would have to pick up the increased welfare burden to support those left without employment through an increase in taxes. Mention has not been made of the political-social problems that may also follow in the wake of lost employment and income. One only needs to look elsewhere, such as Humboldt County, to obtain some idea of how this scenario may develop.

Problems Perceived by the Desert Mining Industry.

In the questionnaire to the desert mining producers, we asked respondents what effect they thought the California Desert Protection Act would have upon their operations in the desert. As may be expected the responses were varied. A sampling of these included:

1. Would have to close down because of lack of raw materials needed in my operation.
2. Our mine would be depleted in a few years and without the ability to replenish reserves locally, we would have to go out of business and layoff employees.
3. Would stop all exploration and go out of state in the future.
4. Eventually it would affect the agricultural segment of California's economy since the company could no longer supply them with raw material.
5. Prices to the consumer would be increased.

6. Construction material prices would rise significantly.
7. Expect having a National park nearby would cause operational problems.
8. Go bankrupt.
9. Would not expand operations.

The respondents brought to our attention that hundreds of employees, who live in the greater Los Angeles metropolitan area and other towns and cities away from the desert, derive their income as a result of desert mining activity. Respondents identified such places as Norwalk, Vernon, Freemont, Santa Fe Springs, South Gate, Torrance, Long Beach, Riverside, Ontario, Bakersfield, El Cajon, Pomona, Cerritos, Anaheim, Rancho Cordova, San Bernardino, San Leandro, Pico Rivera, Hesperia and Sacramento. This is not surprising. There can be no doubt that mineral resource production from the California desert has a major impact outside the local area, and that the impact pervades all of Southern California.

Finally, with respect to mining and the desert environment, California mining controls are stringent as compared with those of other states. environmental impacts are assessed before new operations are started and reclamation is required to restore the beauty and recreational value of mining land. It is clear from the previous economic analysis that a significant amount of mining is being carried on in the the desert, and some of this activity has been ongoing for over 100 years, without destroying the scenic value of the area. The mining industry does little that threatens desert ecosystems. Surface transportation takes place on maintained roads. Cyanide solution leach operations require complete recovery and recycling of the solution to make them profitable—and thus they are safe for the environment.

In summary, the CDPA would have a substantial negative impact upon California's economy. Southern California in particular would be hard hit. There would be a great loss in jobs, income, tax revenues—and at the same time a substantial increase in environmental degradation that would be lasting. For these reasons, the CDPA represents legislation at its worst.

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APPENDIX I
MINERAL PRODUCER QUESTIONNAIRE

MINERAL PRODUCERS QUESTIONNAIRE

Please answer all of the following questions. Your company's answers will be added to that of other desert producing companies to produce the economic report described in the cover letter. In no case will an individual company's data be disclosed. Your responses to this questionnaire will be returned to you, along with a draft copy of the report for your final release. Every effort will be taken to assure the confidentiality of the information you supply. Thank you.

1. Mine location(s):

2. Nearest town(s):

3. Processing plant location:

4. Nearest town:

5. Do you have (other) current deposits located in the desert area? (See map "Proposed Desert Legislation" for an outline of the desert area.)

6. Mineral Commodity Produced:
   a. What consumer goods are produced from the material supplied from your operations?

   b. Are there other end uses (i.e. industrial, agricultural) for your product(s)?

   c. As accurately as possible, please indicate what percentage of your commodity is used in the products and end uses you list above.

   d. Are there unique characteristics about your commodity which distinguish it from other grades or types of that commodity?

   e. If so, are those characteristics reflected in a specialized consumer product or other end use?

   f. Where are the end products fabricated and marketed? (See map of market areas at end of questionnaire. If possible, please use Roman numerals I-IV to designate your market area or areas.)

   g. If California desert sources of this commodity become unavailable, what effect do you think this will have on your end user industries? (See map of "Proposed Desert Legislation")

7. Average Annual Production:

8. Dollar Value:

9. Do you market your product in California?
   a. What percentage is marketed in California?

   b. What percentage is marketed in the U.S.?

   c. What percentage is exported from the U.S.?

10. Total number of company employees in the desert area:
    (See "Proposed Desert Legislation" for map of the desert area)
    a. At the mine?

    b. At the processing plant?

    c. Other employees?

    d. Number independent contractors?

    e. Average annual payroll?

    f. Total employees in California?

    g. Percentage of employees living in the desert area?

    h. Average local expenditures (exclusive of labor)?

    i. If you do not have processing facilities in the desert, where are they located?

    j. Number of employees there?

    k. Other facilities located in southern California? What/Where?

    l. Number of employees at those facilities?

11. Transportation:
    a. Number of truck haulages per year?

    b. Average length of truck haulage?

    c. Number of rail car loadings:

    d. Average rail trip length?

12. Average taxes paid:
    a. Federal?

    b. State?

    c. Local?

    d. Amount of royalties or other fees allocated from your facility to local school districts/governments.

13. Do you feel the desert area is important to your future resources and production ability?

14. Cranston Bill Impact:
    a. What do you believe the impact on your firm will be from proposed desert wilderness legislation (Senate Bill 7.) now and in the long term?

    b. Have you compiled any economic data on that impact?

15. Will your reserves be depleted in:
    a. 5-10 years?
    b. 10-20 years?
    c. greater than 20 years?

16. Where do you plan to acquire new reserves if S.7 passes?

17. How essential are your product(s) to our
   a. national security,
   b. the national economy,
   c. the California economy and
   d. the local economy.

18. Are there other major, traceable economic impacts of the mining industry on the local economy not included in the questions listed above?

19. Comments

Completed by:

Company:

Telephone:

Return to: Shirley Anderson
Department of Marketing
School of Business Administration & Economics
California State University
Northridge, CA 91330

Questions: (213) 820-3591 or (818) 885-2458

MARKET AREAS

APPENDIX II
ECONOMIC IMPACTS OF DESERT MINING INDUSTRY CUTBACKS ON SOUTHERN CALIFORNIA (SOUTHERN CALIFORNIA I-O MODEL)

EFFECTS OF CESSATION OF DESERT MINING IN 5-COUNTY REGION ON S. CALIFORNIA

(EMPLOYMENT IN JOBS, NOT FULL-TIME EQUIVALENTS)
(DOLLAR FIGURES IN MILLIONS)

	EMPLOYMENT	OUTPUT	WAGES	VALUE ADDED
AGRICULTURE	-225.9	-9.881	-1.432	-3.445
AGRI. SERV., FORESTRY, & FISH	-43.9	-1.913	-.566	-.986
MINING	-6983.2	-1331.415	-166.491	-663.364
CONSTRUCTION	-725.3	-27.648	-18.206	-21.428
MANUFACTURING	-1475.2	-289.494	-33.252	-69.975
TRANSPORT. & PUBLIC UTILITIES	-2276.6	-254.699	-71.648	-134.352
WHOLESALE	-1702.0	-98.317	-44.662	-76.473
RETAIL TRADE	-2746.9	-79.637	-34.103	-53.031
FINANCE, INS., & REAL ESTATE	-1070.3	-120.583	-24.845	-88.690
SERVICES	-3006.8	-153.565	-53.170	-93.239
GOVERNMENT	-97.8	-11.244	-2.196	-4.730
ADMIN. AUXILIARY	.0	.000	.000	.000
TOTAL	-20353.9	-2378.397	-450.572	-1209.713
MULTIPLIERS	2.669	1.766	2.339	1.791

WAGES-NET OF TAXES= -413.098

ST TAXES-MINING = -31.478
INDIRECT ST TAXES = -32.053
TOTAL STATE TAXES = -63.531

LOC TAXES-MINING = -14.035
INDIRECT LOC TAXES= -24.817
TOTAL LOCAL TAXES = -38.852

OTHER VALUE ADDED = -694.238
TOTAL VALUE ADDED = -1209.719

TOTAL INITIAL DISTURBANCE ($ MILLIONS) = -1346.485

EFFECTS PER MILLION DOLLARS OF INITIAL DISTURBANCE

EMPLOYMENT	=	15.1(JOBS)
INCOME	= $	334628.40
STATE TAXES	= $	47182.85
LOCAL TAXES	= $	28854.39
VALUE ADDED	= $	898422.74

EFFECTS OF CESSATION OF DESERT MINING IN 5-COUNTY REGION ON S. CALIFORNIA

(EMPLOYMENT IN JOBS, NOT FULL-TIME EQUIVALENTS)
(DOLLAR FIGURES IN MILLIONS)

	EMPLOYMENT	OUTPUT	WAGES	VALUE ADDE'
AGRICULTURE	-225.9	-9.881	-1.432	-3.445
DAIRY PROD., POULTRY, & EGGS	-43.2	-3.220	-.274	-.855
MEAT ANIMALS & MISC. LIVESTOCK	-27.4	-3.087	-.174	-.481
COTTON	-.1	-.008	-.001	-.002
GRAINS, & MISC. CROPS	-3.0	-.296	-.019	-.154
TOBACCO	.0	.000	.000	.000
FRUITS, NUTS, & VEGETABLES	-83.7	-2.171	-.530	-1.215
FOREST PROD.	.0	.000	.000	.000
GREENHOUSE & NURSERY PROD.	-68.4	-1.100	-.434	-.737
AGRI. SERV., FORESTRY, & FISH	-43.9	-1.913	-.566	-.986
AGRI. SERVICES (07)	-42.2	-1.107	-.498	-.511
FORESTRY (08)	-.1	-.047	-.004	-.028
FISHING, HUNTING, &TRAPPING (09)	-1.6	-.759	-.064	-.447
MINING	-6983.2	-1331.415	-166.491	-663.364
METAL MINING (10)	-25.1	-2.465	-.787	-1.442
ANTHRACITE MINING (11)	0.0	0.000	0.000	0.000
BITUM. COAL & LIGNITE (12)	-.5	-.102	-.031	-.064
OIL & GAS EXTRACTION (13)	-123.2	-25.520	-3.497	-16.543
NONMETAL MIN.-EX. FUELS (14)	-6834.4	-1303.328	-162.176	-645.314
CONSTRUCTION	-725.3	-27.648	-18.206	-21.428
GENERAL BLDG. CONTRACTORS (15)	.0	.000	.000	.000
HEAVY CONST. CONTRACTORS (16)	.0	.000	.000	.000
SPECIAL TRADE CONTRACTORS (17)	-725.3	-27.648	-18.206	-21.428
MANUFACTURING	-1475.2	-289.494	-33.252	-69.975
FOOD & KINDRED PROD. (20)	-185.9	-29.859	-3.744	-7.877
TOBACCO MANUFACTURES (21)	-.7	-.010	-.003	-.005
TEXTILE MILL PROD. (22)	-12.0	-1.255	-.201	-.393
APPAREL & OTHER PROD. (23)	-88.8	-3.680	-1.013	-1.226
LUMBER & WOOD PROD. (24)	-9.7	-.598	-.148	-.225
FURNITURE & FIXTURES (25)	-38.9	-2.098	-.576	-.826
PAPER & ALLIED PROD. (26)	-63.5	-6.937	-1.377	-2.193
PRINTING & PUBLISHING (27)	-97.2	-9.556	-1.918	-3.031
CHEMICALS & ALLIED PROD. (28)	-157.1	-23.206	-4.192	-9.409
PETROLEUM & COAL PROD. (29)	-115.9	-145.599	-3.905	-19.958
RUBBER & MISC. PLASTICS (30)	-38.6	-3.391	-.736	-1.373
LEATHER & LEATHER PROD. (31)	-13.5	-.531	-.168	-.239
STONE, CLAY, & GLASS (32)	-85.9	-7.324	-1.834	-3.118
PRIMARY METAL PROD. (33)	-166.6	-19.251	-4.405	-5.883
FABRICATED METAL PROD. (34)	-103.5	-9.096	-2.335	-3.377
MACHINERY, EXCEPT ELEC. (35)	-177.9	-17.457	-4.464	-7.489
ELECTRIC & ELEC. EQUIP. (36)	-42.8	-3.639	-.866	-1.326
TRANSPORTATION EQUIPMENT (37)	-39.6	-3.223	-.655	-.990
INSTRUMENTS & REL. PROD. (38)	-5.4	-.404	-.121	-.200
MISC. MANUFACTURING IND'S (39)	-31.7	-2.380	-.588	-.836
TRANSPORT. & PUBLIC UTILITIES	-2276.6	-254.699	-71.648	-134.352
RAILROAD TRANSPORTATION (40)	-542.4	-40.490	-18.198	-21.871
LOCAL PASS. TRANSIT (41)	-91.4	-4.968	-1.267	-3.497
TRUCKING & WAREHOUSING (42)	-969.0	-68.916	-31.250	-49.361
WATER TRANSPORTATION (44)	-14.2	-1.438	-.340	-.559
TRANSPORTATION BY AIR (45)	-67.9	-6.563	-2.249	-3.858
PIPE LINES-EX. NAT. GAS (46)	-12.2	-3.201	-.403	-2.193
TRANSPORTATION SERVICES (47)	-74.4	-3.056	-1.569	-1.833
COMMUNICATION (48)	-174.9	-20.326	-5.675	-14.190
ELEC., GAS, &SANITARY SERV. (49)	-330.1	-105.741	-10.698	-36.991

WHOLESALE	-1702.0	-98.317	-44.662	-76.473
WHLSALE-DURABLE-GOODS (50)	-1339.9	-76.104	-35.561	-60.935
WHLSALE-NONDURABLE GOODS (51)	-362.0	-22.213	-9.101	-15.538
RETAIL TRADE	-2746.9	-79.637	-34.103	-53.031
BLDG. MAT.-GARDEN SUPPLY (52)	-114.3	-3.912	-1.945	-2.967
GENERAL MERCH. STORES (53)	-493.0	-10.593	-5.465	-8.548
FOOD STORES (54)	-221.7	-6.482	-3.367	-5.222
AUTO. DEALERS-SERV. STAT. (55)	-509.9	-16.571	-8.503	-13.045
APPAREL & ACCESS. STORES (56)	-195.2	-4.090	-2.097	-3.154
FURNITURE & HOME FURNISH. (57)	-115.9	-3.615	-1.960	-2.941
EATING & DRINKING PLACES (58)	-727.3	-23.336	-6.010	-10.025
MISCELLANEOUS RETAIL (59)	-369.5	-11.037	-4.756	-7.129
FINANCE, INS., & REAL ESTATE	-1070.3	-120.583	-24.845	-88.690
BANKING (60)	-416.9	-19.954	-8.978	-15.285
CREDIT AGENCIES EX. BANKS (61)	-84.3	-5.865	-2.601	-3.072
SECURITY, COMM. BROKERS (62)	-27.4	-2.477	-1.325	-1.830
INSURANCE CARRIERS (63)	-177.7	-11.636	-4.542	-5.418
INS. AGENTS, BROKERS (64)	-53.0	-4.664	-1.509	-2.852
REAL ESTATE (65)	-283.8	-73.596	-5.088	-58.791
COMB. REAL ESTATE, INS. (66)	-2.6	-.687	-.047	-.549
HOLDING-OTH. INV.. OFF'S (67)	-24.5	-1.704	-.756	-.892
SERVICES	-3006.8	-153.565	-53.170	-93.239
HOTELS & OTHER LODGING (70)	-125.7	-4.164	-1.270	-1.880
PERSONAL SERVICES (72)	-215.4	-7.455	-2.635	-4.453
BUSINESS SERVICES (73)	-857.9	-47.950	-15.592	-29.429
AUTO REPAIR,SERV.,GARAGES (75)	-182.5	-24.536	-3.216	-11.284
MISC. REPAIR SERVICES (76)	-100.2	-5.066	-1.641	-3.032
MOTION PICTURES (78)	-11.2	-1.036	-.334	-.473
AMUSEMENT & RECREATION (79)	-102.0	-4.696	-2.143	-2.938
HEALTH SERVICES (80)	-643.3	-32.756	-15.033	-21.772
LEGAL SERVICES (81)	-61.6	-5.166	-2.095	-3.874
EDUCATIONAL SERVICES (82)	-172.8	-3.870	-1.906	-2.539
SOCIAL SERVICES (83)	-175.3	-3.315	-1.533	-2.042
MUSEUMS,BOTAN-ZOO.GARDENS (84)	-1.8	-.033	-.015	-.021
MEMBERSHIP ORGANIZATIONS (86)	-252.9	-4.783	-2.212	-2.946
MISCELLANEOUS SERVICES (89)	-104.2	-8.740	-3.545	-6.555
GOVERNMENT	-97.8	-11.244	-2.196	-4.730
ADMIN. AUXILIARY	.0	.000	.000	.000
TOTAL	-20353.9	-2378.397	-450.572	-1209.713
MULTIPLIERS	2.669	1.766	2.339	1.791

WAGES-NET OF TAXES= -413.098

ST TAXES-MINING = -31.478
INDIRECT ST TAXES = -32.053
TOTAL STATE TAXES = -63.531

LOC TAXES-MINING = -14.035
INDIRECT LOC TAXES= -24.817
TOTAL LOCAL TAXES = -38.852

OTHER VALUE ADDED = -694.238
TOTAL VALUE ADDED = -1209.719

TOTAL INITIAL DISTURBANCE ($ MILLIONS) = -1346.485

EFFECTS PER MILLION DOLLARS OF INITIAL DISTURBANCE
EMPLOYMENT = 15.1(JOBS)
INCOME = $ 334628.40
STATE TAXES = $ 47182.85
LOCAL TAXES = $ 28854.39
VALUE ADDED = $ 898422.74

EMPLOYMENT BY OCCUPATION TABLE

ENGINEERS	-334.8
AERONAUT. ENGINEERS	-1.8
CHEMICAL ENGINEERS	-21.1
CIVIL ENGINEERS	-28.4
ELEC. ENGINEERS	-40.8
IND. ENGINEERS	-29.9
MECH. ENGINEERS	-34.7
METAL & MTRLS ENGNRS	-4.0
MINING-PETRO ENGNRS	-142.6
SALES & NEC ENGNRS	-31.7
COMPUTER SPECIALISTS	-110.4
COMPUTER PROGRAMMERS	-62.7
COMPUTER ANALYSTS	-40.3
CMPTR SPCLSTS & NEC	-7.5
HEALTH PROFESSIONALS	-234.8
HEALTH TECHNOLOGISTS	-47.2
NURSES, THERPSTS,...	-110.9
PHYS. ,DENT.,...	-76.8
ENG. & SCI. TECHS	-249.3
AGRI BIO TECHNICIANS	-5.3
CHEMICAL TECHNICIANS	-39.6
DRAFTSMEN	-67.6
ELECTRCL TECHNICIANS	-26.5
INDUST ENGNR TECHNCS	-3.5
MECH. ENG. TECH.	-1.1
MATH TECHNICIANS	-.1
NEC TECHNICIANS	-105.5
TEACHERS, EX. COLLEG	-84.8
PRE K, K-6 TEACHERS	-39.3
7-12 TEACHERS	-45.6
WRITERS,ARTS,ENTERT.	-169.7
EDITORS + REPORTERS	-20.8
PUBLIC RELATIONS	-30.4
NEC MEDIA WKRS,ACTRS DESGNRS,PHOTOGRPHRS	-118.5
RELIG,SOC,TEACH PROF	-201.2
RELIGIOUS WORKERS	-68.2
SOCIAL SCIENTISTS	-39.9
SOC & REC WORKERS	-79.7
POST-SEC TEACHERS	-13.4
PROF., TECH. NEC	-765.3
ACCOUNTANTS	-266.2
AIRLINE TECHNICIANS	-26.4
ARCHITECTS	-6.4
FARM AND ENVIRONMENT	-5.1
LAWYERS AND JUDGES	-71.9
LIBRARIANS	-8.0
BIO & PHYS SCIENTSTS	-211.8
MATH SPECIALISTS	-7.4
SYSTEMS ANALYSTS	-19.4
LABOR RELATION WRKRS	-93.2
NEC RSRCH WRKRS	-16.7
NEC TECHNCS & ENGNRS	-26.5
VOCATNL & ED CNSLRS	-6.3

MANAGERS & ADMINIST.	-2288.1
FINANCIAL MANAGERS	-146.2
FARM PRODUCTS MANGRS	-8.1
WHOLSL & RETL BUYERS	-40.7
HEALTH ADMINISTRATRS	-17.7
INSPECTORS	-2.3
NEC PUBLC ADMNSTRTRS	-6.8
RAILROAD CONDUCTORS	-38.6
RESTAURANT MANAGERS	-96.7
SALES MANAGERS	-146.7
COLLEGE ADMNSTRTRS	-1.3
1-12 SCHOOL ADMINS	-6.3
NEC ADMINISTRATORS	-1776.8
SALES WORKERS	-1189.7
SALES & ADVERT AGNTS	-20.0
INSURANCE AGENTS	-82.7
REAL ESTATE AGENTS	-124.8
STOCK & BOND BROKRS	-18.9
NEC SALES WORKERS	-943.2
CLERICAL WORKERS	-3290.2
INSURANCE ADJUSTERS	-24.9
INFO PROCESS WRKRS	-208.1
SECRETARIES	-741.6
NEC CLERICL & KINDRD	-2315.5
CONST. CRAFTSMEN	-1155.2
ELECTRIC LINEMEN	-30.9
ELECTRICIANS	-193.0
TELEPHONE INSTALLERS	-52.8
NEC CONSTRUCTION	-878.5
CRAFTSMEN, EX. CONST	-2401.6
FORGE- & HAMMER-MEN	-2.7
FURNITURE FINISHERS	-3.0
LOCOMOTIVE ENGINEERS	-65.4
MACHINISTS	-99.8
REPAIR & MECHANICS	-1029.4
PRINTING TRADES	-33.6
SHEET METAL WORKERS	-17.2
TOOL AND DIE MAKERS	-12.3
NEC CRAFTSMEN	-1138.1
OPERATIVES, EX. TRAN	-3278.6
MACHINE OPERATIVES	-38.1
TEXTILE OPERATIVES	-9.0
NEC OPERATIVES	-3231.4
TRANSP. EQUIP. OPER.	-1607.1
MASS TRANSIT WORKERS	-56.9
RAILROAD BRAKEMEN	-89.3
TRUCK DRIVERS	-1118.9
NEC TRANSIT OPER'S	-342.0
LABORERS	-1102.0
CONSTRUCT LABORERS	-178.5
OTHER LABORERS	-923.5
PERS. SERV. WORKERS	-1665.4
CLEANING WORKERS	-408.3
FOOD SERVICE WORKERS	-632.3
HEALTH ASSTS	-186.9
PERSONAL SERVICE	-292.1
PROTCTV SRVC	-145.8

APPENDIX III
ECONOMIC IMPACTS OF DESERT MINING INDUSTRY CUTBACKS
ON THE 5-COUNTY REGION
(IMPERIAL, INYO, KERN, RIVERSIDE & SAN BERNARDINO)
(5-COUNTY DESERT LOCAL ECONOMY I-O MODEL)

EFFECTS OFCESSATION OF DESERT MINING ON 5-COUNTY REGION OF CALIFORNIA

(EMPLOYMENT IN JOBS, NOT FULL-TIME EQUIVALENTS)
(DOLLAR FIGURES IN MILLIONS)

	EMPLOYMENT	OUTPUT	WAGES	VALUE ADDED
AGRICULTURE	-147.5	-5.638	-.935	-2.143
AGRI. SERV., FORESTRY, & FISH	-22.3	-.629	-.257	-.299
MINING	-6870.3	-1308.952	-163.297	-648.832
CONSTRUCTION	-657.0	-22.527	-14.834	-17.459
MANUFACTURING	-678.9	-73.453	-14.304	-23.494
TRANSPORT. & PUBLIC UTILITIES	-2082.9	-221.466	-63.940	-117.138
WHOLESALE	-1369.0	-69.066	-31.435	-53.900
RETAIL TRADE	-2428.3	-64.331	-27.380	-42.604
FINANCE, INS., & REAL ESTATE	-625.6	-61.831	-11.955	-46.416
SERVICES	-2316.7	-99.347	-34.173	-60.047
GOVERNMENT	-77.7	-9.710	-1.730	-3.994
ADMIN. AUXILIARY	.0	.000	.000	.000
TOTAL	-17276.3	-1936.950	-364.240	-1016.326
MULTIPLIERS	2.266	1.439	1.891	1.504

WAGES-NET OF TAXES= -333.943

ST TAXES-MINING = -31.478
INDIRECT ST TAXES = -24.909
TOTAL STATE TAXES = -56.387

LOC TAXES-MINING = -14.035
INDIRECT LOC TAXES= -21.045
TOTAL LOCAL TAXES = -36.080

OTHER VALUE ADDED = -589.916
TOTAL VALUE ADDED = -1016.326

TOTAL INITIAL DISTURBANCE ($ MILLIONS) = -1346.485

EFFECTS PER MILLION DOLLARS OF INITIAL DISTURBANCE

EMPLOYMENT = 12.8(JOBS)
~~INCOME~~ = $ 270511.90
STATE TAXES = $ 41877.18
LOCAL TAXES = $ 26439.04
VALUE ADDED = $ 754799.20

EFFECTS OF CESSATION OF DESERT MINING ON 5-COUNTY REGION OF CALIFORNIA

(EMPLOYMENT IN JOBS, NOT FULL-TIME EQUIVALENTS)
(DOLLAR FIGURES IN MILLIONS)

	EMPLOYMENT	OUTPUT	WAGES	VALUE ADDED
AGRICULTURE	-147.5	-5.638	-.935	-2.143
DAIRY PROD., POULTRY, & EGGS	-20.5	-1.526	-.130	-.405
MEAT ANIMALS & MISC. LIVESTOCK	-14.3	-1.614	-.091	-.252
COTTON	0.0	-.002	0.000	-.001
GRAINS, & MISC. CROPS	-1.3	-.127	-.008	-.066
TOBACCO	.0	.000	.000	.000
FRUITS, NUTS, & VEGETABLES	-58.7	-1.521	-.372	-.851
FOREST PROD.	.0	.000	.000	.000
GREENHOUSE & NURSERY PROD.	-52.7	-.847	-.334	-.568
AGRI. SERV., FORESTRY, & FISH	-22.3	-.629	-.257	-.299
AGRI. SERVICES (07)	-21.8	-.558	-.251	-.258
FORESTRY (08)	-.4	-.056	-.005	-.033
FISHING,HUNTING,&TRAPPING (09)	-.1	-.014	-.001	-.008
MINING	-6870.3	-1308.952	-163.297	-648.832
METAL MINING (10)	-22.9	-2.212	-.706	-1.294
ANTHRACITE MINING (11)	.0	.000	.000	.000
BITUM. COAL & LIGNITE (12)	.0	.000	.000	.000
OIL & GAS EXTRACTION (13)	-17.3	-3.871	-.530	-2.509
NONMETAL MIN.-EX. FUELS (14)	-6830.1	-1302.870	-162.060	-645.029
CONSTRUCTION	-657.0	-22.527	-14.834	-17.459
GENERAL BLDG. CONTRACTORS (15)	.0	.000	.000	.000
HEAVY CONST. CONTRACTORS (16)	.0	.000	.000	.000
SPECIAL TRADE CONTRACTORS (17)	-657.0	-22.527	-14.834	-17.459
MANUFACTURING	-678.9	-73.453	-14.304	-23.494
FOOD & KINDRED PROD. (20)	-95.3	-11.159	-1.449	-2.768
TOBACCO MANUFACTURES (21)	.0	.000	.000	.000
TEXTILE MILL PROD. (22)	-2.6	-.319	-.050	-.107
APPAREL & OTHER PROD. (23)	-34.5	-1.217	-.335	-.415
LUMBER & WOOD PROD. (24)	-3.4	-.243	-.055	-.090
FURNITURE & FIXTURES (25)	-16.2	-.869	-.245	-.342
PAPER & ALLIED PROD. (26)	-24.2	-2.884	-.575	-.898
PRINTING & PUBLISHING (27)	-59.9	-4.972	-.958	-1.532
CHEMICALS & ALLIED PROD. (28)	-59.4	-12.387	-1.863	-4.035
PETROLEUM & COAL PROD. (29)	-5.9	-4.405	-.193	-.651
RUBBER & MISC. PLASTICS (30)	-13.4	-.898	-.207	-.351
LEATHER & LEATHER PROD. (31)	-1.7	-.120	-.041	-.051
STONE, CLAY, & GLASS (32)	-47.7	-4.959	-1.093	-1.980
PRIMARY METAL PROD. (33)	-122.3	-14.585	-3.591	-4.607
FABRICATED METAL PROD. (34)	-61.7	-4.831	-1.263	-1.810
MACHINERY, EXCEPT ELEC. (35)	-92.5	-6.728	-1.715	-2.867
ELECTRIC & ELEC. EQUIP. (36)	-7.2	-.646	-.153	-.247
TRANSPORTATION EQUIPMENT (37)	-18.9	-1.541	-.332	-.475
INSTRUMENTS & REL. PROD. (38)	-2.3	-.141	-.044	-.069
MISC. MANUFACTURING IND'S (39)	-9.6	-.548	-.141	-.197
TRANSPORT. & PUBLIC UTILITIES	-2082.9	-221.466	-63.940	-117.138
RAILROAD TRANSPORTATION (40)	-525.3	-39.209	-17.623	-21.179
LOCAL PASS. TRANSIT (41)	-100.2	-4.218	-1.075	-2.969
TRUCKING & WAREHOUSING (42)	-918.6	-65.771	-30.111	-47.395
WATER TRANSPORTATION (44)	-2.4	-.150	-.035	-.058
TRANSPORTATION BY AIR (45)	-20.7	-1.151	-.395	-.677
PIPE LINES-EX. NAT. GAS (46)	-3.2	-.597	-.075	-.409
TRANSPORTATION SERVICES (47)	-68.3	-1.901	-1.013	-1.174
COMMUNICATION (48)	-125.5	-13.548	-3.990	-10.054
ELEC.,GAS,&SANITARY SERV. (49)	-318.8	-94.920	-9.624	-33.223

WHOLESALE	-1369.0	-69.066	-31.435	-53.900
WHLSALE-DURABLE-GOODS (50)	-1062.4	-52.506	-24.794	-42.552
WHLSALE-NONDURABLE GOODS (51)	-306.7	-16.559	-6.640	-11.348
RETAIL TRADE	-2428.3	-64.331	-27.380	-42.604
BLDG. MAT.-GARDEN SUPPLY (52)	-109.6	-4.020	-1.866	-2.836
GENERAL MERCH. STORES (53)	-424.1	-8.557	-4.415	-6.904
FOOD STORES (54)	-181.6	-5.230	-2.717	-4.215
AUTO. DEALERS-SERV. STAT. (55)	-440.7	-13.477	-6.907	-10.579
APPAREL & ACCESS. STORES (56)	-157.3	-3.054	-1.568	-2.359
FURNITURE & HOME FURNISH. (57)	-100.1	-2.908	-1.577	-2.366
EATING & DRINKING PLACES (58)	-749.6	-19.569	-5.040	-8.407
MISCELLANEOUS RETAIL (59)	-265.3	-7.516	-3.291	-4.938
FINANCE, INS., & REAL ESTATE	-625.6	-61.831	-11.955	-46.416
BANKING (60)	-257.4	-10.854	-4.883	-8.314
CREDIT AGENCIES EX. BANKS (61)	-91.1	-4.837	-2.145	-2.534
SECURITY, COMM. BROKERS (62)	-9.0	-.868	-.464	-.641
INSURANCE CARRIERS (63)	-43.0	-2.658	-1.037	-1.238
INS. AGENTS, BROKERS (64)	-16.4	-1.066	-.345	-.652
REAL ESTATE (65)	-193.7	-40.057	-2.769	-31.999
COMB. REAL ESTATE, INS. (66)	-4.5	-.937	-.065	-.748
HOLDING-OTH. INV.. OFF'S (67)	-10.4	-.555	-.246	-.290
SERVICES	-2316.7	-99.347	-34.173	-60.047
HOTELS & OTHER LODGING (70)	-69.6	-1.670	-.508	-.754
PERSONAL SERVICES (72)	-177.0	-5.168	-1.863	-3.129
BUSINESS SERVICES (73)	-418.0	-20.799	-6.892	-13.048
AUTO REPAIR,SERV.,GARAGES (75)	-170.7	-20.399	-2.674	-9.382
MISC. REPAIR SERVICES (76)	-157.1	-7.432	-2.446	-4.589
MOTION PICTURES (78)	-17.6	-.458	-.147	-.209
AMUSEMENT & RECREATION (79)	-156.8	-3.548	-1.619	-2.220
HEALTH SERVICES (80)	-552.5	-25.580	-11.656	-16.995
LEGAL SERVICES (81)	-39.8	-2.288	-.928	-1.716
EDUCATIONAL SERVICES (82)	-142.0	-3.098	-1.526	-2.033
SOCIAL SERVICES (83)	-148.0	-2.218	-1.026	-1.367
MUSEUMS,BOTAN-ZOO.GARDENS (84)	.0	.000	.000	.000
MEMBERSHIP ORGANIZATIONS (86)	-204.8	-3.070	-1.420	-1.891
MISCELLANEOUS SERVICES (89)	-62.9	-3.620	-1.468	-2.715
GOVERNMENT	-77.7	-9.710	-1.730	-3.994
ADMIN. AUXILIARY	.0	.000	.000	.000
TOTAL	-17276.3	-1936.950	-364.240	-1016.326
MULTIPLIERS	2.266	1.439	1.891	1.504

WAGES-NET OF TAXES= -333.943

ST TAXES-MINING = -31.478
INDIRECT ST TAXES = -24.909
TOTAL STATE TAXES = -56.387

LOC TAXES-MINING = -14.035
INDIRECT LOC TAXES= -21.045
TOTAL LOCAL TAXES = -36.080

OTHER VALUE ADDED = -589.916
TOTAL VALUE ADDED = -1016.326

TOTAL INITIAL DISTURBANCE ($ MILLIONS) = -1346.485

EFFECTS PER MILLION DOLLARS OF INITIAL DISTURBANCE
EMPLOYMENT = 12.8(JOBS)
INCOME = $ 270511.90
STATE TAXES = $ 41877.18
LOCAL TAXES = $ 26439.04
VALUE ADDED = $ 754799.20

EMPLOYMENT BY OCCUPATION TABLE

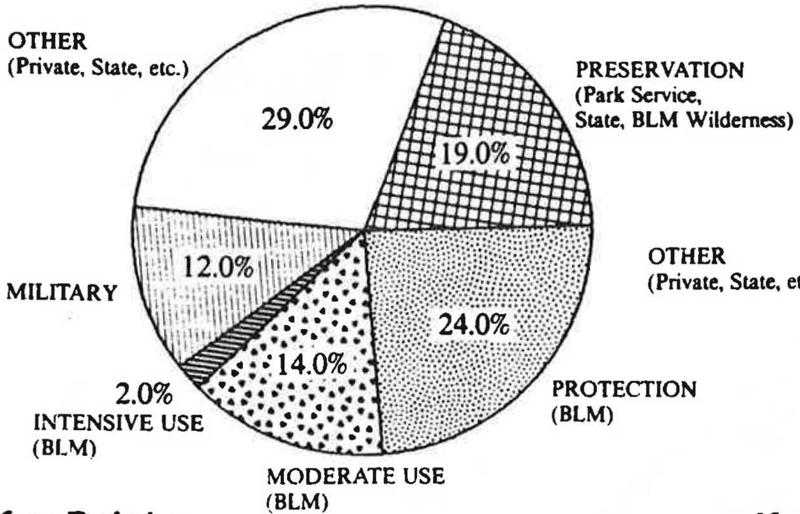
ENGINEERS	-290.6
AERONAUT. ENGINEERS	-1.0
CHEMICAL ENGINEERS	-15.2
CIVIL ENGINEERS	-24.8
ELEC. ENGINEERS	-31.7
IND. ENGINEERS	-22.2
MECH. ENGINEERS	-27.9
METAL & MTRLS ENGNRS	-3.4
MINING-PETRO ENGNRS	-139.6
SALES & NEC ENGNRS	-24.7
COMPUTER SPECIALISTS	-82.6
COMPUTER PROGRAMMERS	-46.9
COMPUTER ANALYSTS	-30.2
CMPTR SPCLSTS & NEC	-5.5
HEALTH PROFESSIONALS	-199.5
HEALTH TECHNOLOGISTS	-40.1
NURSES, THERPSTS,...	-94.8
PHYS. ,DENT.,...	-64.6
ENG. & SCI. TECHS	-207.1
AGRI BIO TECHNICIANS	-3.2
CHEMICAL TECHNICIANS	-29.8
DRAFTSMEN	-56.7
ELECTRCL TECHNICIANS	-20.8
INDUST ENGNR TECHNCS	-2.4
MECH. ENG. TECH.	-.6
MATH TECHNICIANS	-.1
NEC TECHNICIANS	-93.5
TEACHERS, EX. COLLEG	-71.3
PRE K, K-6 TEACHERS	-32.3
7-12 TEACHERS	-39.0
WRITERS,ARTS,ENTERT.	-135.0
EDITORS + REPORTERS	-13.3
PUBLIC RELATIONS	-23.3
NEC MEDIA WKRS,ACTRS DESGNRS,PHOTOGRPHRS	-98.3
RELIG,SOC,TEACH PROF	-164.1
RELIGIOUS WORKERS	-55.9
SOCIAL SCIENTISTS	-28.9
SOC & REC WORKERS	-68.3
POST-SEC TEACHERS	-11.0
PROF., TECH. NEC	-629.1
ACCOUNTANTS	-220.2
AIRLINE TECHNICIANS	-19.5
ARCHITECTS	-4.1
FARM AND ENVIRONMENT	-3.6
LAWYERS AND JUDGES	-55.4
LIBRARIANS	-6.4
BIO & PHYS SCIENTSTS	-196.9
MATH SPECIALISTS	-5.2
SYSTEMS ANALYSTS	-14.2
LABOR RELATION WRKRS	-62.9
NEC RSRCH WRKRS	-12.1
NEC TECHNCS & ENGNRS	-23.6
VOCATNL & ED CNSLRS	-5.0

MANAGERS & ADMINIST.	-1904.9
FINANCIAL MANAGERS	-97.9
FARM PRODUCTS MANGRS	-6.4
WHOLSL & RETL BUYERS	-33.4
HEALTH ADMINISTRATRS	-15.2
INSPECTORS	-1.8
NEC PUBLC ADMNSTRTRS	-5.4
RAILROAD CONDUCTORS	-37.4
RESTAURANT MANAGERS	-98.4
SALES MANAGERS	-116.8
COLLEGE ADMNSTRTRS	-1.1
1-12 SCHOOL ADMINS	-5.2
NEC ADMINISTRATORS	-1485.8
SALES WORKERS	-900.3
SALES & ADVERT AGNTS	-11.7
INSURANCE AGENTS	-22.7
REAL ESTATE AGENTS	-86.4
STOCK & BOND BROKRS	-15.0
NEC SALES WORKERS	-764.4
CLERICAL WORKERS	-2573.8
INSURANCE ADJUSTERS	-7.3
INFO PROCESS WRKRS	-157.7
SECRETARIES	-581.6
NEC CLERICL & KINDRD	-1827.2
CONST. CRAFTSMEN	-1049.1
ELECTRIC LINEMEN	-29.6
ELECTRICIANS	-178.3
TELEPHONE INSTALLERS	-37.9
NEC CONSTRUCTION	-803.4
CRAFTSMEN, EX. CONST	-2131.1
FORGE- & HAMMER-MEN	-2.2
FURNITURE FINISHERS	-2.3
LOCOMOTIVE ENGINEERS	-63.3
MACHINISTS	-81.8
REPAIR & MECHANICS	-919.7
PRINTING TRADES	-22.0
SHEET METAL WORKERS	-13.9
TOOL AND DIE MAKERS	-7.5
NEC CRAFTSMEN	-1018.5
OPERATIVES, EX. TRAN	-2871.0
MACHINE OPERATIVES	-26.5
TEXTILE OPERATIVES	-2.7
NEC OPERATIVES	-2841.9
TRANSP. EQUIP. OPER.	-1489.7
MASS TRANSIT WORKERS	-61.2
RAILROAD BRAKEMEN	-86.2
TRUCK DRIVERS	-1043.8
NEC TRANSIT OPER'S	-298.5
LABORERS	-969.0
CONSTRUCT LABORERS	-163.8
OTHER LABORERS	-805.2
PERS. SERV. WORKERS	-1460.6
CLEANING WORKERS	-297.1
FOOD SERVICE WORKERS	-632.3
HEALTH ASSTS	-160.3
PERSONAL SERVICE	-272.7
PROTCTV SRVC	-98.3

APPENDIX IV
DESERT LAND USE: CURRENT AND PROPOSED

CURRENT LAND USE

(25-million acre California Desert Conservation Area)



Key Points:

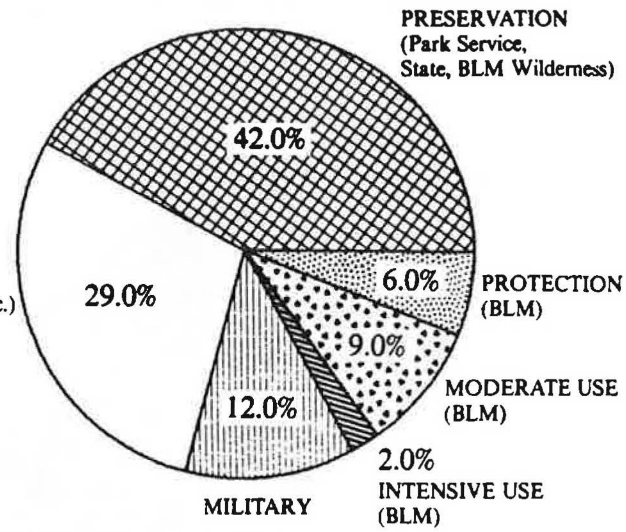
- About one-fifth of the Desert is committed to park and wilderness preservation.
- About one-fourth is managed by BLM primarily to protect cultural and natural values, while allowing other compatible uses.
- About one-eighth is managed by BLM for a variety of uses, balancing development with protection.
- A small fraction (2%), is managed by BLM for intensive use of lands and resources to meet human needs.

PRESERVATION	**4.8 MILLION ACRES**	**19%**
(public vehicle access prohibited in wilderness; restricted in parks)		
National Monuments		
Joshua Tree		560,000 acres
Death Valley		1,957,000 acres
State Park		
Red Rock Canyon		4,500 acres
Wilderness (some in monuments above)		
Park Service Proposed		(1.9 million arces)
Park Service Designated		(467,000 acres)
BLM Proposed		1,900,000 acres
State-Anza Borrego		400,000 acres
PROTECTION	**5.9 MILLION ACRES**	**24%**
BLM, Class L*, limited use		5,900,000 acres
MODERATE USE	**3.3 MILLION ACRES**	**14%**
BLM, Class M*, moderate use		3,300,000 acres
INTENSIVE USE	**500,000 ACRES**	**2%**
BLM, Class I*, intensive use		500,000 acres
MILITARY	**3.1 MILLION ACRES**	**12%**
(no public access) Ft. Irwin, China Lake, Chocolate Mountains, Twenty-Nine Palms, Edwards AFB, etc.		
OTHER	**7.4 MILLION ACRES**	**29%**
(limited or no public use)		
Private, State, other government		

*see front page for explanations of land use classes

PROPOSED LAND USE

(under Senate Bill 7)



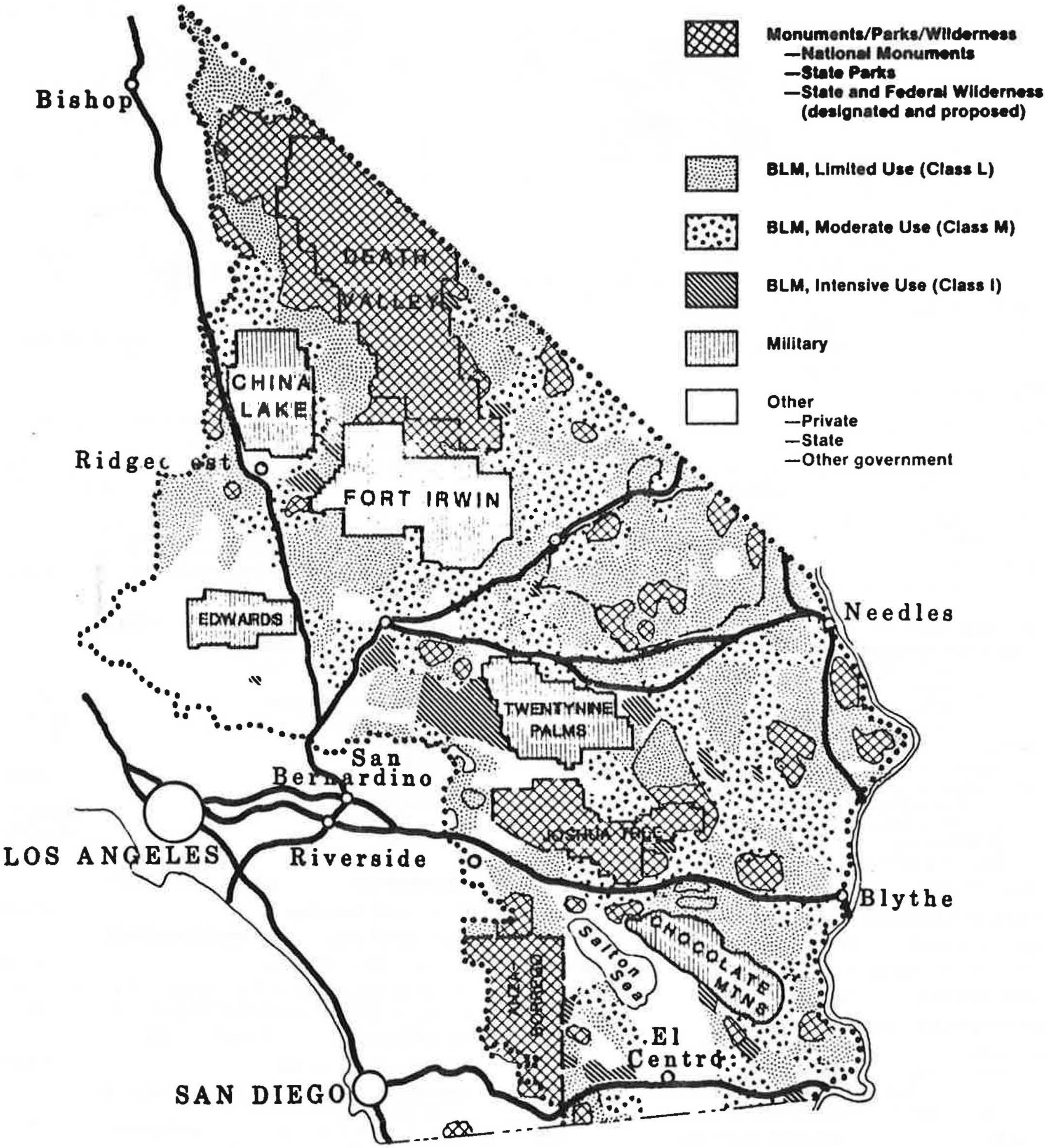
Key Points:

- The amount of land committed to park and wilderness preservation would more than double, from 19% to 42%.
- The amount of land managed by BLM and available for general public use would be reduced from 40% to about 17%, or about one-sixth of the Desert.
- Private land is not immediately affected, but large amounts are inholdings within the proposed parks and wilderness. The legislation calls for acquiring these lands by purchase or exchange, drawing from the 17% of general public use lands remaining.

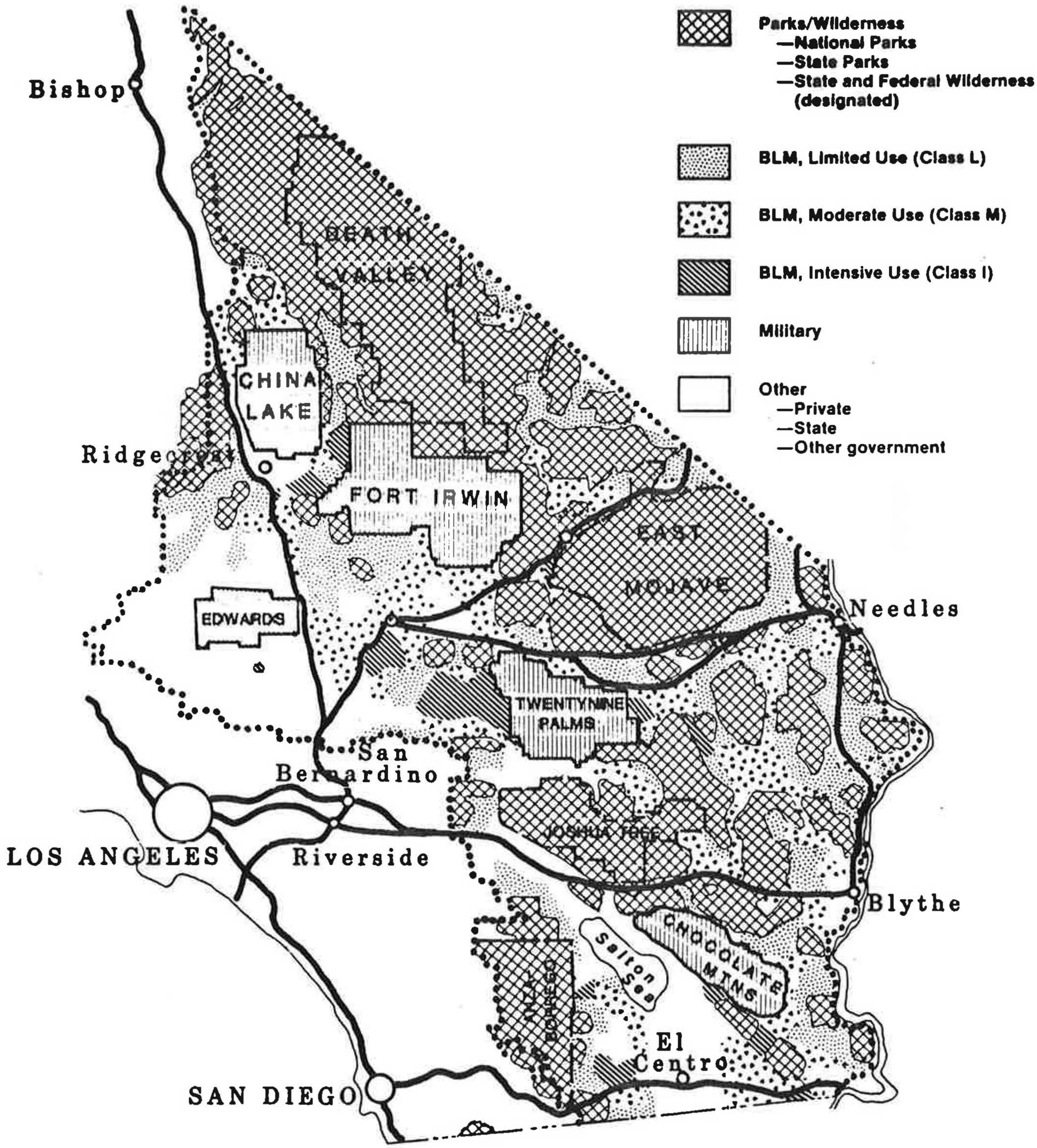
PRESERVATION	**10.4 MILLION ACRES**	**42%**
(public vehicle access prohibited in wilderness; restricted in parks)		
National Parks		
Joshua Tree (expanded)		805,000 acres
Death Valley (expanded)		3,400,000 acres
East Mojave (new)		1,500,000 acres
State Park		
Red Rock Canyon		24,000 acres
Wilderness (some in parks above)		
Park Service		(4,500,000 arces)
BLM		4,300,000 acres
State-Anza Borrego		400,000 acres
PROTECTION	**1.5 MILLION ACRES**	**6%**
BLM, Class L*, limited use		1,500,000 acres
MODERATE USE	**2.1 MILLION ACRES**	**9%**
BLM, Class M*, moderate use		2,100,000 acres
(The above two categories will drop further, as BLM lands will be used to exchange for private inholdings within the parks and wilderness)		
INTENSIVE USE	**500,000 ACRES**	**2%**
BLM, Class I*, intensive use		500,000 acres
MILITARY	**3.1 MILLION ACRES**	**12%**
(no public access) Ft. Irwin, China Lake, Chocolate Mountains, Twenty-Nine Palms, Edwards AFB, etc.		
OTHER	**7.4 MILLION ACRES**	**29%**
(limited or no public use)		
Private, State, other government		

*see front page for explanations of land use classes

CURRENT CALIFORNIA DESERT PLAN



PROPOSED DESERT LEGISLATION



APPENDIX V
RSRI INPUT-OUTPUT MODEL STRUCTURE

REGIONAL SCIENCE RESEARCH INSTITUTE
P.O. Box 3735, Peace Dale, RI 02883
(401-789-5930)

REGIONAL INPUT-OUTPUT MODELING SYSTEM

A. General

RSRI has developed an input-output modeling system which is capable of providing a 500-sector model for any region in the United States from a county up to the multistate and national level. Models for each of the 50 states and a number of substate regions have already been constructed. Several of these are in regular use by public agencies and/or have been applied in specific studies for both public and private clients.

These models are designed particularly for use in regional economic impact analysis. However, the data included in the model system also make it easy to perform other types of analysis, such as industrial targeting.

A model for any region can be supplied for use on the client's own computer, in which case the required data sets and computer programs are provided. RSRI can also perform model runs in accordance with specifications provided by the client. In either case, special features can be added to the model to improve its ease of use in, and applicability to, particular types of analyses.

B. Brief Model Description

The standard RSRI regional model has 493 sectors, plus households. The input-output technological coefficients are based on the 1977 national input-output data provided by the Bureau of Economic Analysis (BEA) of the U.S. Department of Commerce.

The national coefficients are regionalized through the use of regional purchase coefficients (RPCs): these are estimated for the specific region using *Census of Transportation* and *County Business Patterns* data and methods described elsewhere (see list of references). The region specific wages and employment in each sector are also estimated from *County Business Patterns* data, suitably adjusted to be consistent with input-output and Regional Economic Information Service data from BEA. The latter source also provides the data on proprietor's incomes. The most current models use 1985 employment, wages and proprietor's incomes and state and local taxes (or 1984 data where 1985 data are not available).

The regional household columns are based on the *Consumer Expenditure Survey* done in 1980-81 by the Bureau of Labor Statistics. State and local taxes per dollar of household income as well as per dollar output of economic activities are included as part of the model.

The model gives both detailed results and results aggregated to the one-digit and two-digit SIC level for the employment, income, value added, output, and state and local tax effects caused by an exogenous change in the region's economy. A full set of multipliers is also provided. The system includes an occupational-skill matrix which disaggregates employment effects into changes for 95 occupational skill categories; a more detailed (425 category) breakdown is also available.

CALIFORNIA'S UNIQUE GEOLOGIC HISTORY AND ITS ROLE IN MINERAL FORMATION, WITH EMPHASIS ON THE MINERAL RESOURCES OF THE CALIFORNIA DESERT REGION

By

David A. Dellinger, Branch of Western Mineral Resources, U.S. Geological Survey, Menlo Park, CA 94025

Abstract

California's mineral wealth results from its long, complex, and active geologic history. The diversity of rock types in the State and the variety of geologic processes that have acted on these rocks have led to the formation of an unusual diversity of mineral deposits and the creation of some large and very unusual deposits.

Two uncommon geologic events that have occurred in the geologic history of southeastern California have endowed the desert region with very large deposits of two unusual types of mineral deposits. The intrusion of a rare type of igneous rock about 1.4 billion years ago created the largest rare-earth-element deposit in the United States. Much more recently, during the past 20 million years or so, an unusual combination of geologic and climatic conditions have led to the formation of very large borate deposits. Nearly half of the world s present production of borate minerals comes from these desert deposits.

The occurrence of mineral resources in any area is related to the geologic history of the area; the geologic processes that form and subsequently modify the rocks of an area are also responsible for the creation of any mineral deposits found there. California can be divided into eight types of geologic terranes, each of which formed under a certain general set of conditions; each type of terrane thus contains a set of characteristic rock assemblages and mineral deposit types related to its particular geologic history.

The geologic history of California extends over approximately 1.7 billion years, during which the area has been progressively enlarged to the west by the attachment of terranes, some of which were created elsewhere and carried toward the continent (craton) by the motion of tectonic plates. Some of the processes that led to the formation of mineral deposits in California were active before the attachment of these terranes to the craton, whereas others occurred during or after terrane attachment. For example, some types of mineral deposits that occur in California are created only at ocean-floor hot springs; these deposits are found only in oceanic terranes that have become part of the State.

This report briefly describes California's geologic terranes, the origins of those terranes, and the types of mineral deposits typically associated with each terrane. The mineral potential of each of the State's geographic provinces is summarized.

INTRODUCTION

The Federal Land Policy and Management Act of 1976 (Public Law 94—579) requires the Bureau of Land Management (BLM) to inventory and identify the resource and other values of lands under their jurisdiction in the State of California and to report the results of these studies to the public, the President, and the Congress. The law also requires the U.S. Geological Survey and the U.S. Bureau of Mines to conduct mineral resource surveys on certain of these lands; the results of these surveys have been presented in numerous reports that give specific assessments of the identified mineral resources and of the potential for undiscovered mineral resources for individual areas. This report, in contrast, presents a broader, region-by-region summary of the geology, geologic history, identified mineral resources, and mineral resource potential of the State of California, with emphasis on the California desert region, to help integrate the assessments of mineral potential in individual areas. Special treatment is given to the California desert region because of major land-use issues regarding the BLM s California Desert Conservation Area, which occupies much of the desert region.

BACKGROUND

The regional mineral resource assessments presented in this report are taken mostly from earlier compilations by Albers (1981) and Albers and Fraticelli (1984). Their assessments were based on the premise that individual geologic terranes tend to be characterized by particular mineral deposit types; they divided the State into eight types of geologic terranes, each of which contains a characteristic set of deposit types.

The term "geologic terrane," as used here, refers to a discrete portion of the Earth s crust that was created in a specific plate-tectonic setting; in some cases, these terranes formed far from the place where the terrane is now exposed. Each type of geologic terrane is composed of a particular assemblage of rock types; the assemblage found in a given terrane reflects the geologic processes characteristic of the plate-tectonic environment or setting in which it formed. Similarly, the formation of mineral deposits in these rock assemblages results from the action of specific geologic processes associated with particular plate-tectonic settings. Thus, each type of geologic terrane has a unique set of rock types and associated mineral deposit types that reflect the geologic processes characteristic of a particular plate tectonic setting. Specific geologic terrane types and their associated suites of mineral deposits are described below.

Three important conditions complicate the relatively simple portrait of the relations between terranes and mineral deposits presented above. (1) Individual geologic terranes are usually composed of several or many different rock types· however, many types of mineral deposits are restricted to particular types of rock, so potential for these mineral deposits restricted to those parts of a terrane where the appropriate rock type is present. For example, the oceanic terrane that mak up much of California's northern Coast Ranges is composed of numerous rock types, only a fraction of which are ultramafic. Chromite deposits are nearly always found in association with ultramafic rocks, so only those areas in the Coast Ranges that contain exposures of ultramafic rock are considered permissive for the occurrence of undiscovered chromite. (2) Although geologic terranes are defined on the basis of the plate-tectonic environment in which they formed, their subsequent history usually reflects a wide variety of events and processes related to other tectonic regimes. For example, one type of geologic terrane considered in this report is shallow marine carbonate terrane, which formed along what was the western edge of the North American continent (craton) during late Precambrian and Paleozoic time (see Appendix-geologic time chart). During the Mesozoic and early Cenozoic eras, parts of this terrane were intruded by magma generated in and above a slab of oceanic crust as it slid (was subducted) beneath the continent. As a result, the carbonate terrane now includes isolated plutons and dikes that crystallized from this magma, and parts of it are covered by volcanic rocks. The terrane was cut by both high- and low-angle faults during the same period. Mineralization within the carbonate terrane was restricted almost entirely to areas subjected to post-Paleozoic magmatism or faulting-processes associated with tectonic events that occurred long after the terrane had been formed. (3) In many areas, California's geologic terranes are overlain by sedimentary or volcanic material that was deposited during the latest Mesozoic and Cenozoic eras, after the older geologic terranes were assembled into their present configuration by the joining (accretion) of exotic terranes to the craton. These sedimentary and volcanic materials may be largely or entirely independent of the terranes over which they lie, and they should be considered as a separate type of terrane superimposed on the others. Cover terrane, like other terrane types, has a characteristic set of mineral deposits. At present, the most valuable of these are the oil and gas deposits contained within some of these cover rocks and sediments.

In this report, deposits of the metallic commodities are given the most thorough consideration. Occurrences of, and areas permissive for, oil and gas deposits and geothermal energy resources are mentioned briefly if they occur in the province under discussion. Consideration of industrial materials (sand and gravel, aggregate, building stone, and specialized deposits like zeolites, gypsum, and perlite) and other nonmetallic deposits (evaporite or saline deposits, for example) is generally restricted to discussions of resources in the California desert region.

Estimates of mineral resource potential noted in this report are based largely on the compilations of Albers (1981) and Albers and Fraticelli (1984); numerous other published sources have also been used, especially for resource data on the California desert region. This paper is excerpted from Dellinger (1989) for the California Desert Minerals Symposium i. Irvine, Calif., March 3-4, 1989.

GEOLOGIC TERRANES-DESCRIPTIONS, ORIGINS, AND MINERAL DEPOSITS

The major characteristics, origins, and typical mineral deposit types of each of the geologic terrane types in California (fig. 1) are outlined in this section. A more complete account of the mineral resources and potential of each major physiographic region in the State (fig. 2) is presented in the next section.

Cratonic Platform Terrane

Cratonic platform terrane makes up a large part of the eastern California desert region and is therefore considered in some detail. A cratonic platform is part of the stable, tectonically inactive core of a continent, usually consisting of a complex of deformed metamorphic and igneous rocks overlain by flat-lying, stratified sedimentary rocks. In California, the cratonic platform terrane consists of a basement of Precambrian igneous and metamorphic rocks overlain by a thin sequence of upper Precambrian and Paleozoic sedimentary rocks, all intruded by granitoid plutons, mostly of Mesozoic age (Albers, 1981). The complex history of the Precambrian basement rocks is poorly understood at present, due to lack of intense study, scarcity of outcrop, and deformation during and since late Precambrian time. The igneous and sedimentary protoliths of these basement rocks, however, probably formed in plate tectonic environments analogous to those of the present. The most significant mineral deposits associated with the cratonic platform terrane include disseminated-gold deposits, contact metasomatic (replacement) deposits of iron, replacement and vein deposits of silver, lead, or zinc, and the single largest rare-earth-element deposit in the United States (Albers, 1981; Warhol, 1980).

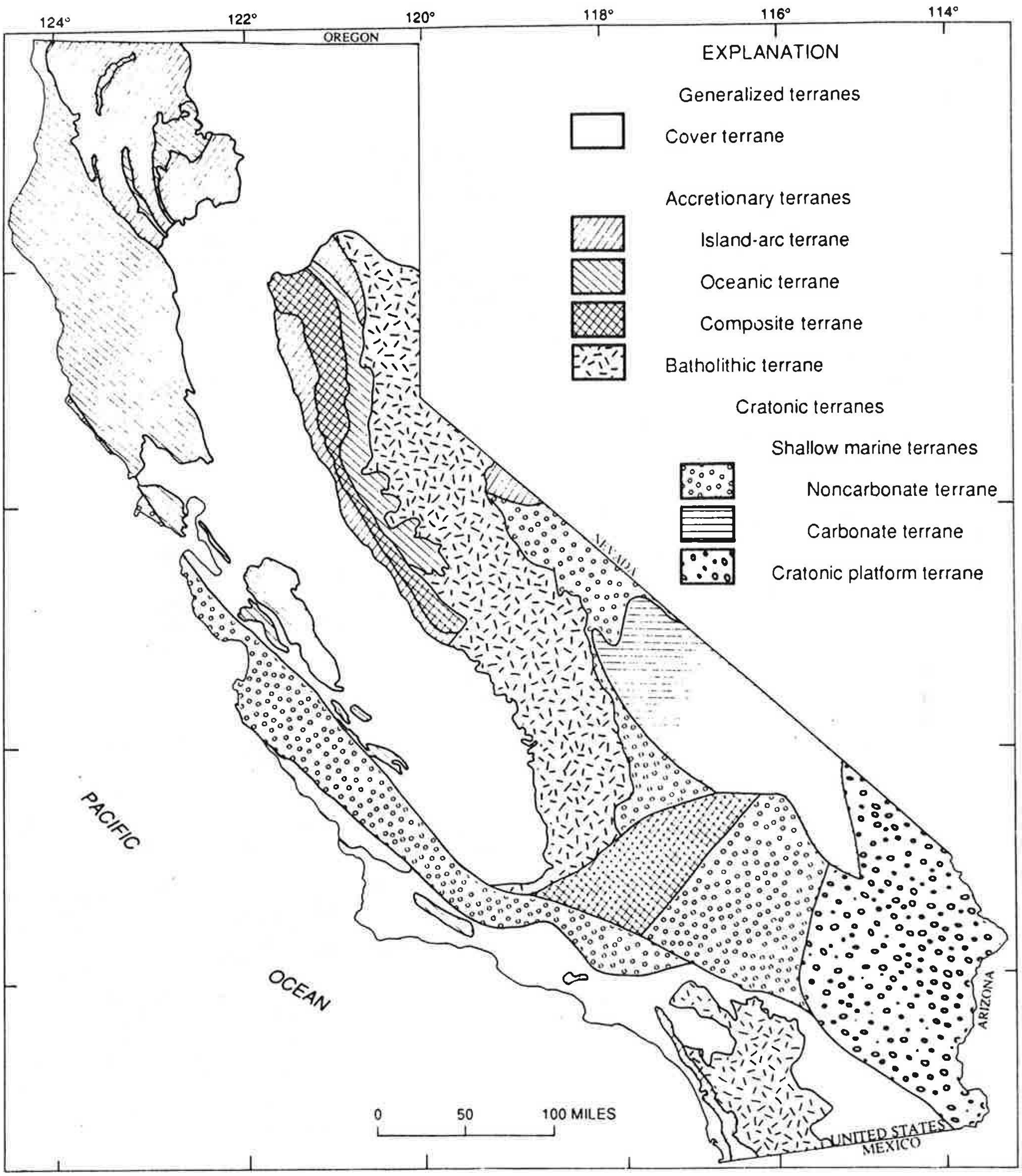


Figure 1.--Map of generalized geologic terranes of California (modified from Albers and Fraticelli, 1984).

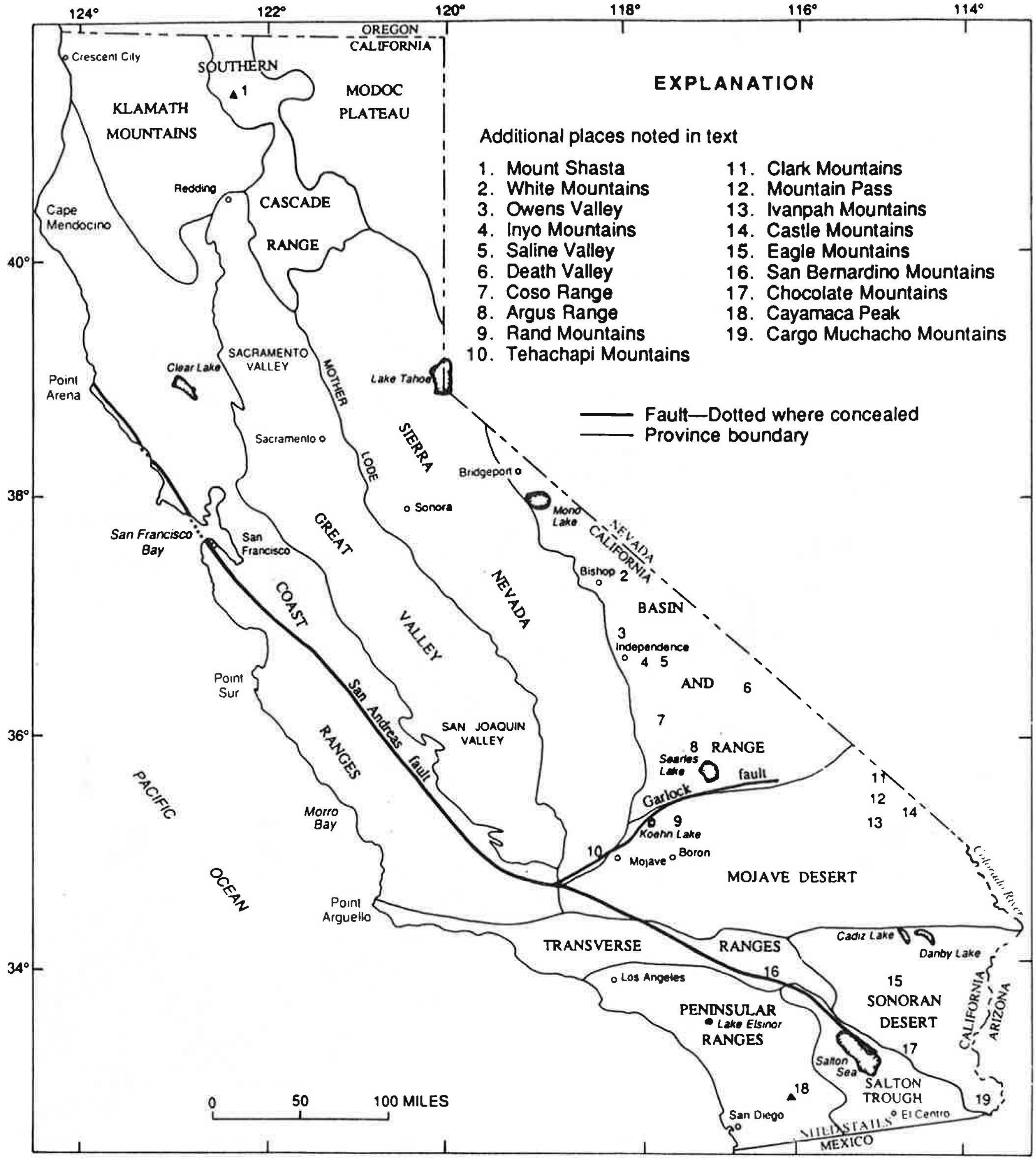


Figure 2.--Map of physiographic provinces, places noted in text, and major active faults of California. Physiographic province names and boundaries modified from Fenneman and Johnson (1946), Hinds (1952), and Norris and Webb (1976).

Shallow Marine Terranes (Cratonic)

Shallow marine terranes consist of rocks that were deposited as a growing wedge of sediments along the continental shelf at the margin of a craton. In California, the thin layer of upper Precambrian and Paleozoic sedimentary rock that overlies the cratonic platform terrane of the Mojave and Sonoran Deserts thickens to the north and west, where it is part of a band of shallow marine sediments that extends from northern Canada to northern Mexico (Albers, 1981). This band can be divided into two parts: an eastern carbonate terrane, discussed first, that grades westward into a noncarbonate terrane dominated by clastic rocks.

Shallow Marine Carbonate Terrane

The shallow marine carbonate terrane consists primarily of thick carbonate units (limestone and dolomite) with very subordinate quartzite and shale. These rocks crop out primarily in the Basin and Range province and the northern Mojave Desert. The most significant mineral occurrences within this terrane are replacement and vein lead-silver-zinc deposits and contact metasomatic and vein tungsten deposits, all found at or near contacts with Mesozoic intrusive rocks (Albers, 1981).

Shallow Marine Noncarbonate Terranes

The western part of the late Precambrian and Paleozoic band of shallow marine deposits, in contrast to the eastern part, consists mostly of quartzite and fine-grained clastic sedimentary rocks. This group of rocks, which crops out north, south, and west of the carbonate terrane, is transitional to deep marine sedimentary rocks found in western Nevada and in isolated exposures in the Sierra Nevada. These rocks host contact metasomatic and vein tungsten deposits, replacement and vein deposits of silver, lead, and zinc, and some gold-quartz vein deposits. The area southwest of the San Andreas fault, between Point Arena and the Transverse Ranges, commonly called the Salinian block, is underlain by metamorphosed shallow marine clastic rocks intruded by Mesozoic granitoid plutons. Metallic mineral deposits are extremely rare in the Salinian block.

Batholithic Terranes

Batholithic terranes are composed primarily of granitoid plutons that rose from zones of melting in and above long-lived subduction zones. Granitoid rocks commonly intrude other terranes, especially those adjacent to the batholiths themselves, but only those areas where the plutons occupy nearly all the exposed surface are referred to as batholithic terranes in this report. There are two such terranes in California, both of Mesozoic age: the Sierra Nevada and the Peninsular Ranges batholiths. The granitoid rocks of batholithic terranes are usually devoid of mineral resources except where they are in contact with other rocks, especially those composed of metasedimentary sequences that contain carbonate rocks. Commodities found within the batholithic terranes include tungsten, molybdenum, and tin in contact metasomatic and vein deposits, iron in contact metasomatic deposits, and gold in quartz veins.

Island-Arc Terranes

Island-arc terranes are typically dominated by volcanic and volcaniclastic rocks of basaltic to andesitic composition, locally intruded by gabbroic to dioritic plutons. These terranes commonly show evidence of compressive deformation, apparently related to the accretion of the terrane onto the continent and to later joining of other terranes. Island-arc terranes in California occur in the Klamath Mountains, the northwestern Sierra Nevada, and the Peninsular Ranges. In the northern areas they are present within larger zones that also include accreted oceanic and composite terranes, all of Paleozoic to early Mesozoic age. Island-arc terranes typically contain lead-silver-zinc-copper-iron massive sulfide deposits, gold-quartz veins, vein and disseminated deposits of copper, contact metasomatic and vein iron and tungsten deposits, and chert-associated and fissure deposits of manganese.

Oceanic Terranes

Modern oceanic crust is typically composed of a simple sequence of igneous rocks, crystallized at midocean ridges, overlain by fine-grained sediments deposited as the ocean floor moves away from the ridge. Ancient oceanic terranes now preserved within continents, however, are usually highly deformed, reflecting the extremely disruptive nature of the processes by which oceanic crust becomes joined to continents. Some oceanic terranes consist of preserved accretionary wedges of material scraped off the top of an oceanic plate as it is subducted; these highly disturbed rocks are known as melange. Other parts of oceanic terranes preserve somewhat less-disrupted deep marine sequences overlying an oceanic igneous sequence. In California, Paleozoic and Mesozoic oceanic terrane underlies much of the Coast Ranges and elongate bands within the western Sierra Nevada and Klamath Mountains. Oceanic melange makes up most of those rocks, especially

in the Coast Ranges, but more complete sequences of deep-water oceanic sedimentary rocks are also present, underlain in some places by igneous oceanic crustal rocks.

Several types of mineral deposits are present within oceanic terranes. Podiform chromium and laterite nickel deposits are associated with ultramafic rock bodies, which are commonly present as tectonic blocks within melange and at the margins of oceanic terranes. Chert-associated manganese, sedimentary iron, and massive sulfide deposits are associated with the upper parts of oceanic igneous sequences, which are also present both as tectonic blocks and at terrane margins. Silica-carbonate mercury deposits, which are associated with altered ultramafic rocks, usually occur in oceanic melange. Vein, fissure, and disseminated deposits of silver, copper, iron, lead, zinc, manganese, and tungsten occur adjacent to and above magmatic intrusions into accreted oceanic terranes.

Composite Terranes

Two terranes in California contain complex mixtures of Paleozoic and Mesozoic rocks that suggest both oceanic and island-arc affinities. One of these is a belt in the western Sierra Nevada, and the other underlies the western Mojave Desert. The histories of these areas are still being studied and actively debated, and no final classification can be presented here. Mineral deposits in these composite terranes are the same as those associated with the oceanic and island-arc terranes.

Cover Terranes

Many parts of California have been covered by volcanic and sedimentary rocks deposited since the accretion of various oceanic and island-arc terranes onto the edge of the continent was completed in the latest part of the Mesozoic era. These materials cover large areas of the State: the Modoc Plateau, the Southern Cascade Range, the Great Valley, much of the coastline between Morro Bay and the Mexico border, and widespread areas in the California desert. Mineral resources in these cover rocks and sediments include all of the State s oil and gas deposits, placer deposits of gold and other heavy metals, volcanogenic uranium and gold, hot-spring mercury and gold, borate deposits, and deposits of many types of industrial minerals.

TECTONIC HISTORY OF CALIFORNIA

A detailed account of the tectonic history of California, which spans at least 1.7 billion years and remains the subject of active debate among geologists, is far beyond the scope of this report. The following highly simplified and generalized account is a summary largely excerpted from Dickinson (1981).

Little is known about the early geologic history of California. The oldest rocks in the state record a metamorphic event that occurred 1.7 billion years ago, and there is considerable evidence for an episode of alkaline plutonism about 1.4 billion years ago (DeWitt and others, 1987). The continent may have extended much farther west during this period; some geologists believe a western extension of North America was rifted away during the Late Precambrian.

During latest Precambrian and early Paleozoic time the west edge of the North American continent was bounded by a passive margin similar to that of the present North American Atlantic coast; cratonic crystalline rocks were overlain by a wedge of shallow marine sedimentary rocks that formed the continental shelf. During this period, marine sediments were deposited on and adjacent to the craton.

From late Paleozoic through early Mesozoic time, the northwest edge of the continent was characterized by a complex pattern of offshore island arcs and marginal seas, probably similar to that of the western Pacific Ocean today. Several of the island-arc, oceanic, and composite terranes of California were created during this interval, although they may have been far from the continent when they formed. By the end of early Mesozoic time, the seas separating these island arcs from the continent had closed, and the easternmost of the oceanic and island-arc terranes of the western Sierra Nevada and the Klamath Mountains became attached to the craton, expanding the continent to the west.

Subduction moved closer to the continent in middle Mesozoic time; the west margin of the continent during the last two-thirds of the Mesozoic era was broadly similar to that of the present-day west edge of South America. This type of margin is characterized by a deep trench separated from its associated continental volcanic arc by an accretionary wedge of disrupted oceanic material (melange), scraped off the subducting plate, and a forearc basin in which volcanogenic sediments from the arc are deposited. The batholithic terranes of the Sierra Nevada and the Peninsular Ranges formed in this setting; they represent roots of a continental magmatic arc, now exposed by uplift and erosion of the volcanic cover. This continental magmatic arc penetrated the cratonic terranes of the present-day California desert region, creating the Mesozoic plutonic and volcanic rocks that underlie much of the region (Tosdal and others, in press); the arc was probably also the source of the plutons in the Salinian block of the southern Coast Ranges. Additional oceanic, island-arc, and composite terranes of the western Sierra Nevada and Klamath Mountains were also added to the continent during this period, as one or more island

arcs collided with the continental margin. Rocks of the oceanic terranes of the Coast Ranges, consisting mostly of melange (but including less-disrupted sequences of sediments), formed just landward of the trench during late Mesozoic time, and the Great Valley sequence of sediments filled a forearc basin that separated the magmatic arc from the trench.

During the later part of the Cenozoic era, subduction in the southern half of present-day California began to give way to transform motion along faults of the San Andreas system, and the rocks southwest of the fault were transported hundreds of miles northwestward. North of Cape Mendocino, where the San Andreas fault veers westward into the Pacific Ocean, subduction continued, and the accompanying magmatism resulted in the late Cenozoic and Quaternary volcanism that characterizes the Modoc Plateau and the Cascade Range. Crustal extension (stretching) in eastern California and Nevada during this period led to the formation of the elongate mountains and valleys that characterize the Basin and Range province.

The coastal region from Morro Bay to Mexico is covered by Cenozoic sedimentary rocks, and the Great Valley is filled to great depths with late Mesozoic and Cenozoic sediments shed from the Sierra Nevada and the Coast Ranges. Older terranes beneath the Cascade Range and Modoc Plateau areas are completely hidden beneath late Cenozoic to Recent volcanic rocks. Each of these areas is classified as cover terrane.

CALIFORNIA MINERAL POTENTIAL

In this section, the mineral resources of each of the major physiographic regions in California (fig. 2) are considered separately. The province names and boundaries follow or are modified from those of Fenneman and Johnson (1946), Hinds (1952), and Norris and Webb (1976). Most of the physiographic provinces are composed of more than one geologic terrane, so they often have more than one set of associated mineral deposit types. The California desert region is discussed here in greater detail than the other regions in the State.

A simple classification system for mineral resource potential is used in this report. Areas are considered to be permissive for the occurrence of mineral deposits if they contain rock assemblages commonly associated with one or more types of mineral deposits. In general, areas are classified as permissive for the occurrence of mineral deposits if they were classified as geologically favorable by Albers and Fraticelli (1984). (The word favorable, in reference to mineral potential, is now usually applied to relatively small areas that have other characteristics, in addition to rock assemblage, that are similar to those of areas known to contain mineral deposits.) In some cases, the areas classified as permissive in this report contain smaller areas that are considered favorable for the occurrence of mineral deposits, but the identification of such areas is beyond the scope of this report.

California Desert Region

Introduction

The California desert region includes all or parts of three different physiographic provinces: the Basin and Range province in the north, the Mojave Desert province in the middle, and the Sonoran Desert in the southeast. The region is bounded on the northwest by the Sierra Nevada and Tehachapi Mountains, on the southwest by the eastern Transverse Ranges and the Peninsular Ranges, and on the east by the Nevada State line and the Colorado River. The Basin and Range province is separated from the Mojave Desert by the Garlock fault and a projected eastward extension of the fault; the boundary between the provinces is gradational in the east, but quite sharp along the Garlock fault itself. The boundary between the Mojave and Sonoran Deserts is arbitrary but corresponds roughly with a change in average elevation; the mean elevation of the Mojave Desert is about 2,500 feet, while elevations in the Sonoran Desert are generally much lower. The Mojave and Sonoran Deserts are characterized by low mountain ranges rising out of an alluvial cover of varying thickness; these low ranges have no particular orientation in most areas, but in some places they have a generally northwesterly trend. In contrast, the Basin and Range province is characterized by elongate, approximately north-south-trending mountain ranges and basins. In California, elevations in the Basin and Range province range from below sea level in Death Valley to over 14,000 feet in the White Mountains. Drainage is internal throughout the California desert region except in the eastern part of the Sonoran Desert province, which is drained into the Gulf of California via the Colorado River.

The desert region in California is geologically different from the rest of the State in several aspects, which are reflected in the variety and types of mineral deposits of the region. First, the crystalline rocks that form the basement of the region are the oldest rocks in the State. One type of important mineral deposit (rare-earth-element-rich carbonatite) is restricted to a single known occurrence in these rocks, and the potential for additional rare-earth-element deposits of this type in the State is restricted to the California desert region. Second, during parts of the late Cenozoic era an unusual combination of climatic and geologic conditions led to the formation of extensive boron-rich evaporite deposits. Borate deposits in the United States are confined to the California desert and the adjacent region of Nevada, and all present production is from California. Finally, the region has an unusually complex geologic history. Many rock types are present, and the entire area has been subjected to long episodes of intrusive and extrusive magmatism, accompanied by periods of both compressional and

extensional deformation. Most areas are cut by faults related to one of the deformational episodes, and many of the rocks that are not themselves magmatic in origin show evidence of alteration due to magmatic heat and fluids. Most types of metallic mineral deposits, worldwide, are related (directly or indirectly) to heat and fluids associated with the rise and emplacement or eruption of magma; faults commonly serve both as channels for mineralizing fluids and as sites of mineral deposition. In summary, the California desert region has the necessary ingredients for the formation of many different types of mineral deposits: a great variety of rock types and compositions, long episodes of magmatism, and an abundance of faults in a variety of orientations.

Geologic History of the Region

The beginnings of the geologic history of the California desert region are enigmatic. The oldest rocks in the region are schists and gneisses that formed during a metamorphic event about 1.7 billion years ago, but the ages of the igneous and sedimentary rocks from which they formed are unknown. At least two intrusive episodes apparently occurred during the more than 1-billion-year interval between the earliest metamorphism and the beginning of shallow marine deposition in late Precambrian time, but little else is known about the history of the region during this time interval. From an economic standpoint, the most significant of these intrusive pulses was the emplacement of alkaline plutonic rocks, including carbonatite, about 1.4 billion years ago. Some workers (for example, Stewart, 1972, and Dickinson, 1981) hypothesize that the continent extended much farther west during this period and that the western part was rifted away during the late Precambrian, thus setting the stage for shallow marine sedimentation. The remaining Precambrian crystalline rocks form the basement of the California desert s cratonic terranes.

Beginning in the late Precambrian and continuing throughout the Paleozoic, shallow marine sediments were deposited on the margin of the craton. These rocks are thin on the cratonic platform terrane (south of the Garlock fault), but they thicken considerably in the Basin and Range province to the north. Oceanic sedimentary rocks and island-arc(?) volcanic rocks of about the same age are present in the northwestern Mojave Desert, but their origin is uncertain; for the purposes of this report they are grouped as composite terrane.

Beginning in the late Triassic, the magmatic arc that formed the Sierra Nevada batholith also extended through the present-day desert region. Much of the Mesozoic era was characterized by repeated episodes of deformation, evidence of which is preserved in the geologic record as east-directed thrust faults in the northeastern part of the region and east-verging folds in the southwest. Mesozoic plutonic rocks make up more than half the exposed rocks in the Mojave and Sonoran Deserts (Dibblee, 1980) and are less common (but nevertheless abundant) in the Basin and Range province. Mesozoic volcanic rocks are also present but not widespread, probably because most were removed by erosion during the Cenozoic era. Magmatic activity in the California desert region continued into the Cenozoic, but most of the exposed magmatic rocks of Cenozoic age are volcanic rather than plutonic. In most cases the upper levels of these relatively young magmatic systems have not yet been removed by erosion, and their deep intrusive roots remain unexposed.

In late Cenozoic time the entire region was transformed into an area of internal drainage by uplift along its west margin. Local uplifts and depressions associated with crustal extension occurred at many places in the region, creating numerous closed drainage basins. These basins became sites of deposition for lacustrine (lake) sediments, volcanic and volcaniclastic rocks, and (or) evaporite deposits similar to those now forming in dry lakes or playas at many places in the California desert region. As a result of the lack of external drainage, thick Quaternary sedimentary sequences cover much of the region, especially the western part of the Mojave Desert, and relatively thin sequences of sediment locally cover bedrock adjacent to the mountains.

History of Mineralization

The history of mineralization of the California desert region parallels its geologic history. The length and complexity of the geologic history has provided numerous opportunities within the past 1.7 billion years for the concentration and deposition of mineral resources. Two of the most notable deposit types-the rare-earth-element deposit at Mountain Pass and numerous borate deposits in the region-are, respectively, among the oldest and youngest kinds of deposits found in the region.

The most significant Precambrian deposit-forming event was the intrusion of alkaline plutons about 1.4 billion years ago. Among these plutons was at least one carbonatite intrusion, now exposed at Mountain Pass, near the Nevada border. Other rare-earth-element-bearing carbonatite bodies may exist in the California desert region, but none are presently known.

Little mineralization of late Precambrian or Paleozoic age is known. The thick sequences of limestone and dolomite that were deposited in the shallow marine carbonate terrane of the northern Mojave Desert and Basin and Range province, however, later served as host rocks to numerous deposit types associated with the intrusion of magmas. Reaction between the carbonate rocks and younger hydrothermal fluids was an essential part of the deposit-forming process.

Most of the metallic mineral deposits in the California desert region were formed in association with Mesozoic and Cenozoic magmatism and deformation. Emplacement of magma into the upper crust provided both the heat and the fluids that are critical for the formation of many types of mineral deposits, and faults provided channels for the movement of the fluids. The details of mineral deposit genesis are beyond the scope of this report, but a short description of the general features of magmatic mineral deposit formation may be useful.

During the rise and emplacement of magma bodies into overlying rocks, magmatic fluids are released into the surrounding rocks, and meteoric water already in the rocks becomes heated. Under appropriate conditions, reactions between the host rocks and these fluids result in mineral deposits. In some cases these deposits occur adjacent to magmatic intrusions; the tungsten and the iron contact metasomatic (skarn) deposits of the California desert region, for example, occur along the contacts between granitoid rocks and carbonate rocks. Often, however, mineral deposits occur at some distance from intrusions; many kinds of vein deposits and replacement deposits form where hydrothermal fluids, traveling along faults or fractures, react with appropriate host rocks or simply precipitate metallic minerals as they cool. The lead-silver-zinc replacement deposits and many kinds of vein deposits (including gold, silver, tungsten, lead, zinc, and copper) are examples found in the California desert region.

During late Cenozoic time, an unusual combination of geologic, topographic, and climatic conditions led to the formation of large borate and other evaporite mineral deposits. Evaporite deposits form when large amounts of water are removed from a closed basin by evaporation, creating first a saline lake and then a dry lake or playa. Borate minerals, like other evaporites, may precipitate either when saturation is reached in a drying saline lake or when boron-rich thermal water enters and reacts with water in a cooler saline lake. Three factors are needed to create borate deposits: (1) basins with no external drainage; (2) periods of relatively arid climate, to maintain or increase the salinity of the lakes by high evaporation; and (3) a source of boron. The extensional tectonic regime that characterized much of the desert region during the later part of Cenozoic time led to the formation of closed basins. The dry climate may have resulted from (or at least been enhanced by) the rise of substantial mountain ranges to the west that created rain shadows over the desert region. The boron is believed to have originated in boron-rich hot springs (Carpenter, 1980; Siefke, 1980). The borate deposits of the California desert region are among the largest and most productive in the world; in recent years, production from the desert region has made the United States one of the world s two largest producers of borates (Lyday, 1988; Carillo and others, 1987).

More than 60 percent of the California desert surface is covered by alluvial deposits that prevent direct examination and exploration of bedrock. Assuming that the rock types and geologic structures seen in exposures of bedrock continue under this alluvial cover, it is very probable that undiscovered mineral resources similar to those already discovered in exposed bedrock are present beneath the alluvium. Exploration of bedrock beneath sedimentary cover is difficult at present, and production of resources from depth is more expensive than surface mining. Because subsurface data is very scarce, no assessment of the mineral resource potential of bedrock beneath alluvium is included in this report. Future developments in exploration and mining technology, however, are likely to make the discovery and production of buried resources in the California desert region possible and economically feasible.

History of Mineral Resource Production

The earliest development of mineral resources in the California desert region was probably by Native American populations who gathered such materials as clay and turquoise (Davis and Anderson, 1980). Gold and silver mines were in operation by the end of the 18th century, and production has continued intermittently to the present. Most production has been from bedrock, but gold has also been produced from placer deposits in at least three mining districts in the California desert region (Clark, 1980). Accurate production figures for gold and silver are not available, but total production of gold from the California desert region certainly exceeds 3 million ounces, and annual production from the desert region has been rapidly rising during the past 5 years. Gold production from the desert was about 5,000 ounces in 1982, while anticipated production totals for 1987 and 1988 are 255,000 ounces and 305,000 ounces respectively (Anderson, 1987). Total gold production for the State was about 108 million ounces as of 1987, with about a third of that taken from gold-quartz vein deposits in the northern Sierra Nevada. Since 1982, the rate of gold production in California has been more than doubling every year (Lucas, 1988). The largest contact metasomatic iron deposits in the State are located in the California desert region, where well over 100 million tons of ore have been produced (Scott and Wilson, 1980). Other metallic mineral commodities that have been produced in smaller amounts include antimony, bismuth, cadmium, lead, lithium, manganese, magnesium, mercury, tin, tungsten, uranium, vanadium, and zinc (Davis and Anderson, 1980).

Production of nonmetallic mineral commodities also has a long history in the California desert region. Development of borate resources in the region began with production from playas in the 1870s. Most borate production shifted to richer bedded deposits about 1890, except at Searles Lake, where production of borates and other salts from brine continues. Bedded borates (kernite, ulexite, probertite, or colemanite) are mined at Boron and were mined in Death Valley until 1986. In recent years, the California desert region has been the source of all U.S. production and one-third to one-half of the

worldwide production of borates (Lyday, 1988; Carillo and others, 1987). The largest producing rare-earth deposit in the western world is at Mountain Pass (Warhol, 1980); it was discovered in 1949, and development started soon thereafter. During the 20th century, population growth in the California desert region and adjacent areas, especially the Los Angeles an San Diego metropolitan areas, has increased the demand for significant production of industrial materials such as sar gravel, aggregate, perlite, clay, limestone, and gypsum. At present, the value of nonmetallic mineral commodities producea from the California desert region (including borates, rare-earth elements, and industrial minerals) exceeds that of the metallic commodities from the region (Carillo and others, 1987).

Metals

More than half of the exposed bedrock in the California desert region is considered geologically permissive for the existence of undiscovered mineral deposits (Albers and Fraticelli, 1984). These permissive areas, widely scattered throughout the desert, are separated by alluvial cover and by bedrock that is not considered geologically permissive for mineral resources and that lacks known deposits. Alluvium may contain placer deposits of gold or other commodities. About a third of the area underlain by permissive bedrock has numerous known deposits. In order to facilitate description of the mineral resources and potential of the five geologic terranes that underlie this large region, each terrane is discussed separately.

The cratonic platform terrane, which underlies most of the Sonoran Desert and the eastern third of the Mojave Desert, has numerous areas that are geologically permissive for mineral deposits of gold, iron, copper, tungsten, manganese, lead, zinc, or silver. About a third of this area contains known deposits of one or more of these metals. For more than 30 years, most mining activity in the cratonic platform terrane was focused on contact metasomatic iron deposits, but major production of iron ore has ceased. The largest producer of iron ore was the Eagle Mountain iron mine, located in the Eagle Mountains in the southern part of the cratonic platform terrane. It opened in 1948 and produced more than 100 million tons of ore before closing in 1984 (Scott and Wilson, 1980; Burnett, 1985). At present, disseminated-gold deposits are the most important metallic mineral deposits in the region; most present exploration and mining activity in the area is directed toward finding and developing these deposits. Large disseminated-gold deposits include the Mesquite and Picacho mines in the Chocolate Mountains, the Morning Star mine in the Ivanpah Mountains, and the Colosseum mine in the Clark Mountains. These four mines are expected to have combined production of at least 300,000 ounces of gold per year (Anderson, 1987; Lucas, 1988; Carillo and others, 1987). In these deposits, the gold occurs as extremely fine grained particles, usually invisible to the naked eye. The characteristics and settings of disseminated-gold deposits are apparently quite varied. Tosdal and Smith (1987 describe the the Mesquite deposit as a large gneiss-hosted epithermal vein deposit in brecciated or fractured host rock. They associate deposits in the Cargo Muchacho Mountains with aluminous, kyanite-bearing gneisses and schists. Some of the Cargo Muchacho deposits may be metamorphosed gold-skarn deposits (Orris and others, 1987), closely associated with the metasomatic iron (iron skarn) deposits of the region. Bouley (1986) describes the occurrence of disseminated gold in breccia on low-angle detachment faults that cut crystalline and volcanic rocks and cites the Picacho mine as an example. In the Hart mining district, located in the Castle Mountains, disseminated-gold deposits are hosted by volcanic rocks.

Shallow marine noncarbonate terrane underlies the central part of the Mojave Desert, west of the cratonic platform terrane. Much of the exposed bedrock in this area is considered permissive for iron, gold, lead, zinc, or copper, and a few areas are considered permissive for silver, tungsten, or mercury. About a quarter of the area considered permissive for one or more of these commodities contains known mineral deposits. As in the cratonic platform terrane, most known metallic mineral resources occur in contact metasomatic iron deposits and in replacement or vein deposits of the other commodities.

The western Mojave Desert is underlain by terrane of debatable origin. In this report it will be considered to be composite (oceanic and island-arc) terrane, following Albers and Fraticelli (1984). Most of the region is not considered permissive for metallic mineral deposits, but there are significant exceptions to this generalization. Several areas within the region are considered permissive for gold, tungsten, lead, or zinc, and some of these permissive areas contain known deposits of gold. The mineralized area in the vicinity of the Rand Mountains is considered permissive for deposits of tungsten, gold, silver, manganese, and antimony and contains known deposits that include the vein-type tungsten deposit at Atolia and the gold-quartz vein deposits of the Randsburg mining district.

Shallow marine carbonate terrane underlies much of the California Basin and Range province and a corner of the Mojave Desert. Much of the exposed bedrock in this terrane is considered geologically permissive for lead, silver, zinc, tungsten, or silver, and about a quarter of this area contains known deposits of these metals. The major deposits in this area are lead-silver-zinc replacement and vein deposits and contact metasomatic tungsten deposits. An area in the southwestern part of the carbonate terrane, in the vicinity of the Coso and Argus Ranges, is considered geologically permissive for gold, manganese, molybdenum, and mercury, but known deposits are sparse. Berger (1986) describes deposits containing extremely fine grained gold and silver in certain types of carbonate rocks that have been intruded by magma; the large

deposit at the Carlin mine in north-central Nevada is an example. Similar deposits may exist in the shallow marine carbonate terrane of the California desert region.

Shallow marine noncarbonate terrane underlies the part of the California Basin and Range province north and west of the carbonate terrane. Bedrock there is considered permissive for gold, tungsten, lead, silver, zinc, or copper. About a third of this area contains known deposits of one or more of these commodities. As in the adjacent shallow marine carbonate terrane, most of the deposits in this area are contact metasomatic tungsten deposits and lead-silver-zinc replacement and vein deposits.

Special Metals (Rare-Earth Elements, Uranium)

Precambrian rocks at Mountain Pass contain the largest producing rare-earth-element deposit in the western world. Economic deposits of rare-earth elements are commonly found in carbonatite, a rare kind of igneous rock containing carbonate minerals. According to Singer (1986), these deposits typically occur in cratonic terranes and are spatially related to fault lineaments and alkaline volcanism. In the deposit at Mountain Pass, the rare-earth elements occur in the mineral bastnaesite (a fluorocarbonate) that makes up about 10 percent of an approximately 1.4-billion-year-old carbonatite body that intrudes still older gneiss (DeWitt and others, 1987; Woyski, 1980). The rare-earth elements in the Mountain Pass deposit are cerium, lanthanum, neodymium, praesodymium, samarium, gadolinium, and europium, in order of decreasing abundance; cerium and lanthanum make up about 85 percent of the rare-earth elements in the deposit (Warhol, 1980). Although other rare-earth-element deposits are not known in the California desert region, Precambrian crystalline rocks are considered geologically permissive for additional deposits.

Cenozoic intermediate to silicic volcanic rocks throughout the region are considered geologically permissive for uranium deposits, but known deposits are sparse. Sediments derived principally from these rocks are also considered geologically permissive (for example, uranium-bearing volcanogenic sediments are present near the Coso Range).

Nonmetallic Commodities

Among the most important nonmetallic commodities found in the California desert region are borate and associated evaporite minerals and saline brines, collectively known as saline deposits. The origins of these deposits are discussed above. The lower parts of most of the closed basins in the California desert region are considered geologically permissive for saline deposits, and most of them contain known deposits. Examples include Death Valley, Saline Valley, Searles Lake, Cadiz Lake, Danby Lake, and Koehn Lake. Borate minerals do not occur in all of these areas; common salt (sodium chloride) is recovered from saline brine by evaporation at several locations.

Deposits of industrial minerals occur throughout the California desert region. Sand and gravel deposits are abundant in the alluvium that covers much of the region (Leighton, 1980). Notably pure and uniform deposits of limestone and dolomite are present in many of the late Precambrian and Paleozoic carbonate sequences that occur in places in the cratonic platform terrane of the Mojave and Sonoran Deserts and form the shallow marine carbonate terrane of the Basin and Range province (Gray and Bowen, 1980). Development of these deposits has been hindered by the high cost of transporting them to markets along the Pacific coast, but as sources closer to the coastal markets are depleted and desert population centers grow, these resources may become more important. Pumice, perlite, and cinder deposits are mined in several places in the California desert region, and Cenozoic volcanic rocks are geologically permissive for additional deposits of these commodities. Eleven areas in the western Mojave Desert and two areas in the Basin and Range Province contain known zeolite resources (Stinson, 1984).

There are four Known Geothermal Resource Areas (KGRAs) in the California desert region. The largest of these is the Coso field, adjacent to the Coso Range, which is being developed for electric power generation (Collie, 1978; Anderson, 1987). Eight other areas, scattered throughout the California desert region, have known near-surface thermal waters (Majmundar, 1983).

Peninsular Ranges and Salton Trough

The Peninsular Ranges and Salton Trough areas of California are located in the southern part of the State, primarily southwest of the San Andreas fault. The geologic history of the Peninsular Ranges should be considered along with that of Mexico and Central America, as the area has been moved northwestward at least 200 miles since motion along the San Andreas fault began in the Miocene; some evidence, based on paleomagnetic measurements, suggests that the Peninsular Ranges have moved much farther than 200 miles. Most of the region is underlain by a batholithic terrane similar in age and composition to the Sierra Nevada batholith. Granitoid plutons of this terrane intrude an island-arc terrane along the west edge of the range and a shallow marine noncarbonate terrane in the northern part of the area. Tertiary volcanic rocks cover scattered parts of these areas. Details of the geologic history of the Peninsular Ranges are beyond the scope of this report,

but the same kinds of geologic events (if not the same sequence) that created the terranes of the Sierra Nevada northeast of the San Andreas fault must also have led to the formation of the geologic terranes of the Peninsular Ranges.

The Salton Trough is a pull-apart basin created by strike-slip (horizontal) motion on the San Andreas fault. The basin is filled to considerable depths with sediment, but mineral resource potential is restricted to saline (evaporite) deposits at or near the surface. The Salton Trough also has significant known and potential geothermal energy resources.

The most notable mineral deposits in the Peninsular Ranges are lithium minerals and gemstones in pegmatites. Pegmatites are found only in areas underlain by plutonic rock; batholithic terrane in the region is considered geologically permissive for undiscovered lithium and gemstone deposits.

Large metallic mineral deposits have not been discovered in the Peninsular Ranges or Salton Trough provinces, but two areas in the Peninsular Ranges do have numerous small deposits of gold, tungsten, copper, and other metals. Part of the northern Peninsular Ranges, near Lake Elsinor, has deposits of gold, tungsten, copper, antimony, manganese, lead, or zinc. The area northeast of Cayamaca Peak (about 40 miles from San Diego) has deposits of copper, nickel, silver, gold, and manganese. Both areas are considered geologically permissive for the discovery of additional deposits.

Most of the western Peninsular Ranges area is considered geologically permissive for copper, gold, manganese, iron, or nickel, but there are few known deposits in this area. Tertiary volcanic rocks, which occur in scattered localities throughout the eastern Peninsular Ranges, are considered geologically permissive for deposits of uranium, but known deposits are sparse or absent. Areas within several basins in the eastern Peninsular Ranges and parts of the Salton Trough are considered geologically permissive for saline (evaporite) deposits. Some of these areas, including a large area southeast of the Salton Sea, contain known deposits of evaporite minerals or saline brines. The large gypsum deposits near El Centro are an example. The Salton Trough also contains seven KGRAs that together have substantial identified electric-energy potential (Nathenson and Muffler, 1975; Collie, 1978; Majmundar, 1983). Five geothermal power plants are currently operating in these areas. The rest of the Salton Trough area is considered geologically permissive for additional geothermal energy resources.

Transverse Ranges

The Transverse Ranges trend approximately east-west, nearly perpendicular to the generally north-northwesterly grain of most geologic and physiographic features in California. The ranges extend from Point Arguello on the Pacific Ocean to the San Bernardino Mountains in the east, where the province grades into the Mojave and Sonoran Desert provinces. The western part of the Transverse Ranges province is underlain by Cenozoic marine and nonmarine sedimentary rocks. These rocks are not known to contain metallic mineral deposits, but they do contain many reservoirs of oil and gas from which considerable production has taken place. The offshore extensions of the producing formations are also known to contain oil and gas, and development of these deposits is underway.

Noncarbonate shallow marine terrane underlies the eastern Transverse Ranges. About half of this area is considered geologically permissive for gold, copper, lead, zinc, manganese, iron, or titanium, and about half of the geologically permissive area contains known deposits of one or more of these metals. Deposit types include chert-associated manganese, gold-quartz veins, and anorthosite titanium.

Sierra Nevada

The Sierra Nevada extends 400 miles from the Modoc Plateau in the north to the Mojave Desert in the south; it varies in width from 40 to 100 miles. The range is highest and most rugged along much of its east edge, and overall elevation gradually decreases to the west. The range can be divided into western and eastern belts that have geologically different characteristics. The western belt, along the west edge of the north half of the range, consists of Paleozoic to Mesozoic oceanic, island-arc, and composite terranes that are intruded by Mesozoic quartz dioritic to granodioritic plutons. These three terranes form bands that parallel the trend of the range; generally the oceanic band is closest to the core of the range, and the island-arc band lies along the west edge. The eastern belt of the Sierra Nevada is batholithic terrane, composed almost entirely of Mesozoic granodioritic to granitic plutons that enclose remnants of older Mesozoic deep marine volcanic and clastic rocks in its western part and Paleozoic shallow marine quartzose and carbonate rocks in the eastern part. The different geologic characters of the eastern and western belts are reflected in the different mineral deposit types found in these two regions.

The western belt is historically important as the center of the California gold-rush activity in the middle 19th century. The Mother Lode is in the western belt, and about a third of California's total gold production was taken from gold-quartz veins in this region; the belt contains nearly all the large lode-gold deposits in California (Albers, 1981). Virtually the entire western belt is considered geologically permissive for mineral deposits containing gold, chromium, nickel, copper, zinc, manganese, or mercury, and about a third of the belt has numerous known deposits of one or more of these metals. The large

disseminated-gold deposit at Jamestown, southwest of Sonora, lies within the western belt. Gold-quartz vein deposits are found in all three terranes of this belt, but the occurrence of the other common mineral deposit types is more restricted. Podiform chromite and laterite nickel deposits are associated with ultramafic rocks that occur most often within or at the margins of oceanic and composite terranes. Chert-associated manganese deposits occur mostly in oceanic and composite terranes, but they also occur in a small area of island-arc terrane that lies northeast of the oceanic band at the north end of the range. Pyritic massive sulfide deposits are restricted to the island-arc band.

Mineral resources in the batholithic eastern belt of the Sierra Nevada are mostly restricted to roof pendants-bodies of metamorphic rock caught between or within plutons. The majority of granitoid bodies in the batholith are devoid of known mineral deposits (except where they are in contact with roof pendants) and are not considered to be geologically permissive for undiscovered mineral deposits. The most common commodity found in the batholithic terrane is tungsten, which occurs in skarn deposits at contacts between metamorphic carbonate rocks and granitoid plutons. California ranks first in tungsten production in the United States (Carillo and others, 1987), and the Pine Creek deposit near Bishop (east-central edge of the range) is the largest deposit of this type in California.

North of Lake Tahoe, the Sierra Nevada batholith contains a few roof pendants that have deposits of, and are geologically permissive for, tungsten or gold. Much of the area between Lake Tahoe and Bridgeport is considered geologically permissive for gold, tungsten, mercury, manganese, or uranium in skarn deposits in roof pendants and in hot-spring, vein, and other deposits in Cenozoic volcanic rocks, but known deposits are sparse or absent. South of Bridgeport, the batholithic terrane contains numerous roof pendants; collectively, these bodies have numerous deposits of, and are considered to be geologically permissive for, tungsten and molybdenum in skarn deposits, gold in quartz veins, iron in epigenetic magnetite deposits, or chromium in podiform chromite deposits that occur in roof pendants of oceanic affinity along the west edge of the batholith. Batholithic rocks along the central east edge of the Sierra Nevada, from Mono Lake to Independence, contain numerous roof pendants and are considered to be geologically permissive for deposits of tungsten and gold. Deposits of tungsten, gold, or molybdenum occur locally, but known deposits are sparse or absent in most of this area. Most of the Sierra Nevada south of the 36th parallel is considered to be geologically permissive for gold, tungsten, lead, zinc, antimony, or mercury in roof-pendant skarn deposits or in gold-quartz and other vein deposits. Known deposits of gold, tungsten, antimony, or mercury occur in parts of the area, but most of the area lacks known deposits.

Great Valley

The Great Valley, the elongate valley that lies between the Sierra Nevada and the Coast Ranges, is filled to great depths with sequences of marine and nonmarine sediments and sedimentary rocks shed from the Sierra Nevada, the Coast Ranges, and their ancestors since late Mesozoic time. The Great Valley contains no known metallic mineral deposits and is not considered geologically permissive for undiscovered metalliferous deposits. However, the sedimentary rocks of the Great Valley contain oil and natural gas in large quantities. Both oil and gas are present in the southern half of the valley (San Joaquin Valley); the northern section (Sacramento Valley) contains large deposits of dry natural gas. Mercury deposits occur along the boundary between the Great Valley and the Coast Ranges provinces. In this report they are included in the discussion of the Coast Ranges.

Coast Ranges

The California Coast Ranges are divided by the San Andreas fault into two separate regions: the northern Coast Ranges, northeast of the fault, and the southern Coast Ranges, southwest of it. The northern Coast Ranges are underlain entirely by oceanic terrane, while the southern Coast Ranges can be divided into two parallel segments: a wide band of shallow marine noncarbonate terrane lies adjacent to the San Andreas fault, and a narrower band of oceanic terrane lies to the southwest, along the coast from Point Sur to Morro Bay. Much of the southern end of the Coast Ranges is underlain by Cenozoic sedimentary rocks like those that make up much of the western Transverse Ranges.

More than half of the oceanic terrane in both parts of the Coast Ranges is made up of the Franciscan Complex, which consists of blocks of sandstone, graywacke, and chert-greenstone units separated by melange zones that consist of smaller blocks of the above units along with serpentinite, blueschist, eclogite, chert, limestone, and mafic and ultramafic rocks, all in a sheared argillaceous matrix. The most characteristic feature of the Franciscan Complex is its extreme structural disorder, which is thought to have developed as the unit was scraped off a subducting oceanic plate and accreted onto the continent. The entire Franciscan Complex is considered geologically permissive for deposits of chert-associated manganese and silica-carbonate-hosted mercury. Small bodies of ultramafic rock occur locally throughout the Franciscan Complex; areas containing these exposures are considered permissive for podiform chromium deposits. However, only a small part of the area underlain by the Franciscan Complex contains known deposits of any of these commodities. The Coast Ranges oceanic terranes also include large areas underlain by relatively undisturbed Mesozoic marine sedimentary sequences that are not

considered permissive for mineral deposits. Some of the Cenozoic volcanic rocks in the central part of the northern province, between Clear Lake and the San Francisco Bay, are considered permissive for epithermal hot-spring gold and mercury deposits. The McLaughlin gold mine southeast of Clear Lake is an example of a large mine of this type. Significant geothermal energy resources are present in the northern Coast Ranges. The Geysers KGRA, south of Clear Lake, contains the largest geothermal electric-power-generation installation in the world (Majmundar, 1983), and the region surrounding the KGRA is considered geologically permissive for additional geothermal resources (Collie, 1978).

The shallow marine noncarbonate terrane of the southern Coast Ranges (also known as the Salinian block) is composed principally of metamorphosed clastic sedimentary rocks intruded by Mesozoic plutons. Known deposits are extremely rare in this terrane.

Cenozoic sedimentary sequences cover the southern end of the Coast Ranges province and parts of the Salinian block. Some areas within this cover terrane contain known deposits of oil and gas.

Klamath Mountains

The Klamath Mountains province of northern California is a rugged, mountainous region that has a complex geologic history extending from early Paleozoic time to the present. It is composed of oceanic and island-arc terranes of Paleozoic and early Mesozoic age, stacked in a series of generally east-dipping thrust sheets, that are intruded by granitoid plutons of Ordovician to Early Cretaceous age. Most of the rocks in the Klamath Mountains are marine island-arc-related volcanic and sedimentary rocks, but ultramafic and related oceanic igneous rocks also occur throughout the region, especially at the major thrust faults that mark boundaries between the terranes (Irwin, 1981). Two unusually large ultramafic masses are geologically permissive for chromite deposits: the Josephine Peridotite, which straddles the California-Oregon border northeast of Crescent City, and the Trinity ultramafic sheet southwest of Mount Shasta.

The distribution of known mineral deposits and geologically permissive terrane in the Klamath Mountains province is complex, reflecting the complexities of the geology. About three-fourths of the region is considered geologically permissive for gold, chromium, silver, manganese, copper, lead, mercury, iron, tungsten, nickel, zinc, molybdenum, or magnesium, and about a quarter of the area contains known deposits of one or more of these commodities. Bodies of ultramafic rock, many of them quite small, occur throughout the region. All of these bodies are considered geologically permissive for podiform chromite deposits, but most do not contain known deposits. Nickeliferous laterites overlie ultramafic rocks in some places, especially in the western part of the Klamath Mountains province. Gold-quartz vein deposits are also widespread throughout the Klamath Mountains, apparently associated with bodies of granitoid rock that intrude the region. The largest of these is the French Gulch-Deadwood vein system, northwest of Redding, which has yielded about 800,000 oz of gold. Massive sulfide deposits (copper and zinc with associated lead, silver, iron, manganese, and tungsten) occur in Devonian, Permian, and Triassic island-arc terrane (West and East Shasta districts) in the southeastern part of the Klamath region; smaller massive sulfide deposits also are present in metavolcanic rocks farther west. In the western part of the province, small lode-gold deposits are associated with a late Paleozoic or Triassic island-arc terrane, and chert-associated manganese deposits occur in oceanic terrane.

Modoc Plateau and Southern Cascade Range

These two provinces that make up northeastern California are underlain by relatively young volcanic rocks and volcanogenic sediments. The Cascade Range is a chain of high, young volcanos, distributed along an older, late Cenozoic volcanogenic range; it extends from Canada through Washington and Oregon into northern California. The late Cenozoic to Recent volcanic rocks of the Modoc Plateau form an upland of subdued topography. Geologically, the Modoc and Cascade areas differ in style of volcanism; the Cascades are dominated by the products of explosive volcanism, whereas the rocks of the Modoc Plateau are more commonly lava flows. Both of these areas are Cenozoic cover terranes that conceal northern extensions of the Sierra Nevada province and the eastern Klamath Mountains province beneath considerable depths of volcanic rock and volcanogenic sediment.

A few relatively small areas in the Modoc Plateau contain known deposits of gold, mercury, copper, or silver and are considered geologically permissive for the discovery of additional deposits. These deposits are related to rhyolitic intrusions that are scattered throughout the region. Most of the region, however, is devoid of known deposits and is not considered to be permissive for the discovery of mineral resources. Several KGRAs are present in the region, however, and most of the Modoc Plateau is considered geologically permissive for additional geothermal resources (Collie, 1978; Majmundar, 1983).

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GEOLOGIC TIME CHART

Terms and boundary ages used by the U.S. Geological Survey in this report

EON	ERA	PERIOD		EPOCH	AGE ESTIMATES OF BOUNDARIES IN MILLION YEARS (Ma)
Phanerozoic	Cenozoic	Quaternary		Holocene	0.010
				Pleistocene	1.7
		Tertiary	Neogene Subperiod	Pliocene	5
				Miocene	24
			Paleogene Subperiod	Oligocene	38
				Eocene	55
				Paleocene	66
	Mesozoic	Cretaceous		Late	96
				Early	138
		Jurassic		Late Middle Early	205
		Triassic		Late Middle Early	~240
	Paleozoic	Permian		Late Early	290
		Carboniferous Periods	Pennsylvanian	Late Middle Early	~330
			Mississippian	Late Early	360
		Devonian		Late Middle Early	410
		Silurian		Late Middle Early	435
		Ordovician		Late Middle Early	500
		Cambrian		Late Middle Early	[1]~570
Proterozoic	Late Proterozoic				900
	Middle Proterozoic				1600
	Early Proterozoic				2500
Archean	Late Archean				3000
	Middle Archean				3400
	Early Archean				(3800?)
pre-Archean[2]					4550

[1]Rocks older than 570 Ma also called Precambrian, a time term without specific rank.
[2]Informal time term without specific rank.

MINERAL RESOURCE ASSESSMENTS UNDER THE WILDERNESS PROGRAM OF THE U.S. GEOLOGICAL SURVEY AND THE U.S. BUREAU OF MINES

By

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Assessment of mineral resource potential for approximately 13 million acres of land administered by the U.S. Bureau of Land Management (BLM) is the subject of the 12-year-long multi-agency Wilderness Program. The Federal Land Policy and Management Act of 1976 requires that the U.S. Geological Survey (USGS) and the U.S. Bureau of Mines (USBM) conduct mineral surveys on all land that is recommended to Congress for designation as Wilderness under the National Wilderness Preservation System. USGS studies are designed to provide a scientific basis for assessing the potential for undiscovered mineral resources by determining geologic units and structures, possible environments of mineral deposition, presence of geochemical and geophysical anomalies, and applicable ore-deposit models. USBM evaluates identified (known) resources by collecting data on current and past mining activities and through field examination of mines, prospects, claims, and mineralized areas.

Since the beginning of the Program, the USGS and USBM have assessed the mineral resources and resource potential for nearly 300 BLM wilderness study areas in 10 western states. In the late 1970's and early 1980's, results of studies were published in 27 USGS Miscellaneous Field Studies Maps. Some early 1980's assessments and recent minor studies were published in 37 USGS Open-File Reports. The major part of the Program's results, mostly completed in the mid-1980's, are contained in 148 USGS Bulletins.

Among the more significant contributions of the Wilderness Program are the assessments of 46 wilderness study areas totaling about 2.52 million acres in and near the California Desert. This region includes exploration targets for bulk minable, low-grade disseminated gold deposits such as that being mined at the Mesquite mine in the Chocolate Mountains, and is the subject of wilderness legislation in the 101st Congress. Of the wilderness study areas studied by USGS and USBM in the California Desert, 13 have high potential for undiscovered gold resources; seven of these also have high potential for undiscovered silver resources. Of these, three have high potential for undiscovered copper, lead, and zinc resources. Thirteen other areas have moderate potential for undiscovered gold resources; nine of these have moderate potential for undiscovered silver resources. Of these, three also have moderate potential for undiscovered copper, lead, and zinc resources. There are seven study areas in the California Desert that have zones that contain identified resources of gold and silver; an additional two areas have identified resources of gold. One study area contains identified resources of copper, lead, and zinc; an additional area has identified resources of copper. The results and interpretations contained in the mineral resource publications of the USGS and USBM have been a major source of objective information with which to make land-use-policy decisions.

Table 1.-- List of joint U.S. Geological Survey/U.S. Bureau of Mines publications on the mineral resources of U.S. Bureau of Land Management-managed wilderness study areas in or managed from California.
[MF, U.S. Geological Survey Miscellaneous Field Studies Map; Bull, U.S. Geological Survey Bulletin; OF, U.S. Geological Survey Open-File Report]

Name	BLM number	Reference	Publication
Baker-Cypress, Timbered Crater	(CA-000-ISA1) (CA-030-201)	Peterson and others, 1981	MF-1214-B
Bighorn Mountains	(CDCA-217)	Matti and others, 1982b	MF-1493-A
Bristol/Granite Mountains	(CDCA-256)	Howard and others, 1987	Bull. 1712-C
Carson Iceberg	(NV-030-532)	Keith and Miller, 1988	OF 88-0273
Castle Peaks	(CDCA-266)	Miller and others, 1986	Bull. 1713-A
Chemehuevi Mountains	(CDCA-310)	Miller and others, 1983	MF-1584-A
Chemehuevi/ Needles	(AZ-050-004)	John and others, 1988	OF 87-0586
Chuckwalla Mountains	(CDCA-348)	Powell and others, 1984a	OF 84-0674
Cinder Cones	(CDCA-239)	Wilshire and others, 1987	Bull. 1712-B
Coxcomb Mountains	(CDCA-328)	Calzia and others, 1983	MF-1603-A
Dry Valley Rim	(CA-020-615)	Diggles and others, 1988b	Bull. 1706-D
Eagle Mountains	(CDCA-334)	Powell and others, 1984b	OF 84-0631
East Fork High Rock Canyon	(CA-020-914/ NV-020-006)	Ach and other, 1987	Bull. 1707-B
El Paso Mountains	(CDCA-164)	Diggles and others, 1985a	Bull. 1708-C
Fish Creek Mountains	(CDCA-372)	Todd and others, 1987a	Bull. 1711-C
Fort Piute	(CDCA-267)	Nielson and others, 1987	Bull. 1713-C

Table 1. (continued)

Name	BLM number	Reference	Publication
Funeral Mountains	(CDCA-143)	Armstrong and others, 1987a	Bull. 1709-B
Golden Valley	(CDCA-170)	Diggles and others, 1985b	Bull. 1708-D
Greenwater Valley	(CDCA-148)	Armstrong and others, 1987b	Bull. 1709-B
High Rock Canyon	(CA-020-913B)	Turrin and others, 1988	Bull. 1707-D
Hunter Mountain	(CDCA-123)	McKee and others, 1984	OF 84-0638
Indian Pass, Picacho Peak	(CDCA-355) (CDCA-355A)	Smith and others, 1987	Bull. 1711-A
Inyo Mountains	(CDCA-122)	McKee and others, 1985	Bull. 1708-A
Jacumba	(CDCA-368)	Todd and others, 1987c	Bull. 1711-D
Kelso Dunes	(CDCA-250)	Yeend and others, 1984	OF 84-0647
King Range, Chemise Mountain	(CA-050-112) (CA-050-111)	McLaughlin and others, 1981	MF-1196-C
Kingston Range	(CDCA-222)	Calzia and others, 1987	Bull. 1709-D
Little High Rock Canyon	(CA-020-913/ NV-020-008)	Keith and others, 1987	Bull. 1707-C
Little Sand Spring	(CDCA-119)	Wrucke and others, 1984b; 1985	OF 84-557; OF 85-215
Massacre Rim	(CA-020-1013)	Bergquist and others, 1988a	Bull. 1707-E
Mecca Hills	(CDCA-343)	Morton and others, 1988	Bull. 1710-C
Morongo	(CDCA-218)	Matti and others, 1987	Bull. 1710-B
Newberry Mountains, Rodman Mountains	(CDCA-207)	Cox and others, 1987	Bull. 1712-A

Table 1. (continued)

Name	BLM number	Reference	Publication
Nopah Range	(CDCA-150)	Armstrong and others, 1987c	Bull. 1709-C
North Algodones Dunes	(CDCA-360)	Smith and others, 1984	OF 84-630
Orocopia Mountains	(CDCA-344)	Haxel and others, 1988	Bull. 1710-E
Owens Peak, Tulare and Kern Counties	(CA-010-026)	Diggles and others, 1986	Bull. 1705-A
Owens Peak and Little Lake Canyon, Inyo and Kern Counties	(CDCA-158) (CDCA-157)	Diggles and others, 1985c	Bull. 1708-B
Owlshead Mountains	(CDCA-156)	Koch and others, 1984a	OF 84-755
Palen-McCoy	(CDCA-325)	Stone and others, 1985	Bull. 1710-A
Panamint Dunes	(CDCA-127)	Kennedy and others, 1984	OF 84-678
Pinnacles Wilderness Contiguous	(CA-040-303)	Ludington and others, 1987	Bull. 1705-C
Pit River Canyon	(CA-020-103)	Sherlock and Campbell, 1986	Bull. 1706-E
Providence Mountains	(CDCA-263)	Goldfarb and others, 1988	Bull. 1712-D
Rockhouse	(CA-010-029)	Diggles and others, 1989	Bull. 1705-E [in press]
Sacatar Meadows	(CA-010-027)	Diggles and others, 1988a	Bull. 1705-D
Saline Valley, Lower Saline Valley	(CDCA-117) (CDCA-117A)	Wrucke and others, 1984a	OF 84-560
Santa Rosa Mountains	(CDCA-341)	Calzia and others, 1988	Bull. 1710-D

Table 1. (continued)

Name	BLM number	Reference	Publication
Sawtooth Mountains, Carrizo Gorge/Eastern McCain Valley	(CA-060-024B) (CA-060-025A)	Todd and others, 1987b	Bull. 1711-B
Sheep Hole-Cadiz	(CDCA-305)	Marsh and others, 1982a	OF 82-957
Sheldon Contiguous	(CA-020-1012)	Bergquist and others, 1988b	OF 88-246
Skedaddle Mountain	(CA-020-612)	Diggles and others, 1988c	Bull. 1706-C
Slate Range	(CDCA-142)	Koch and others, 1984b	OF 84-754
South Providence Mountains	(CDCA-262)	Miller and others, 1985	MF-1780-A
South Providence Mountains	(CDCA-262)	Miller and others, 1984	OF 84-679
Southern Inyo	(CA-010-056)	Conrad and others, 1987	Bull. 1705-B
Southern Otay Mountain, Western Otay Mountain	(CA-060-029) (CA-060-028)	Todd and others, 1988	Bull. 1711-E
Tunnel Ridge	(CA-030-402)	Kennedy and others, 1985	MF-1810-A
Tunnison Mountain	(CA-020-311)	Peterson and others, 1988	Bull. 1706-B
Turtle Mountains	(CDCA-307)	Howard and others, 1988	Bull. 1713-B
Twin Peaks	(CA-020-619A)	Vercoutere and others, 1988	Bull. 1706-A
Whipple Mountains and Whipple Mountains Addition	(CDCA-312) (AZ-050-010)	Marsh and others, 1988; 1982b	Bull. 1713-D; OF 82-956
Whitewater	(CDCA-218)	Matti and others, 1982a	MF-1478-A
Wildrose Canyon	(CDCA-132)	Conrad and others, 1984	OF 84-665

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MINING AND THE CALIFORNIA DESERT

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Summary

Considerably less than one percent of the population and economy of California is involved with nonfuel minerals production. Although the California Desert Conservation Area produces significant quantities of some minerals, much of the value of mineral production is derived from private lands that would be unaffected by any legislation. Additionally, the bulk of the remaining value of mineral production from the California Desert is confined to the low unit-value construction materials, many of which are available elsewhere.

Claimholders on federal lands in the CDCA would be protected by valid existing rights from any change in land status due to legislation. Current holders of mining claims on these lands need only prove the presence of economic quantities of minerals in order to continue to hold title to these commodities.

Nowhere in the California Desert are there any current mining operations or reserves of strategic or critical materials. While it is often asserted that the CDCA holds many strategic or critical deposits, the Office of Technology Assessment maintains that all but 14 commodities can be obtained from domestic or secure foreign sources. None of the 14 strategic or critical materials identified by the OTA are currently produced in the California Desert.

Mineral mining proponents claim that the proposed California Desert Protection Act would close off areas of mineral mining potential from possible exploration and future production. Yet, an analysis of gold mines in California reveals that 90 percent of all current and proposed gold mines in the state are located on sites with historical mining activity. The proposed legislation has excluded, to the extent possible, all sites with significant historical mineral production in order to minimize the impact of desert protection on future mineral endeavors.

I. Purpose and Structure

This paper analyzes the role of mining and mineral processing in the state of California with emphasis on the California Desert Conservation Area (CDCA). In particular, the study assesses the potential impact of wilderness designation on current and future mineral production from public lands in the CDCA.

This report begins with an introduction to the California Desert region and a description of proposed legislation affecting the region, followed by an overview of the CDCA and California mining industries. Section IV details the mining practices on public lands and the related importance of the Mining Law of 1872. The paper next considers the issue of strategic and critical materials in the California Desert and then concludes with a discussion of the problem of determining the mineral production potential of the vast public land acreage in the California Desert.

II. Introduction

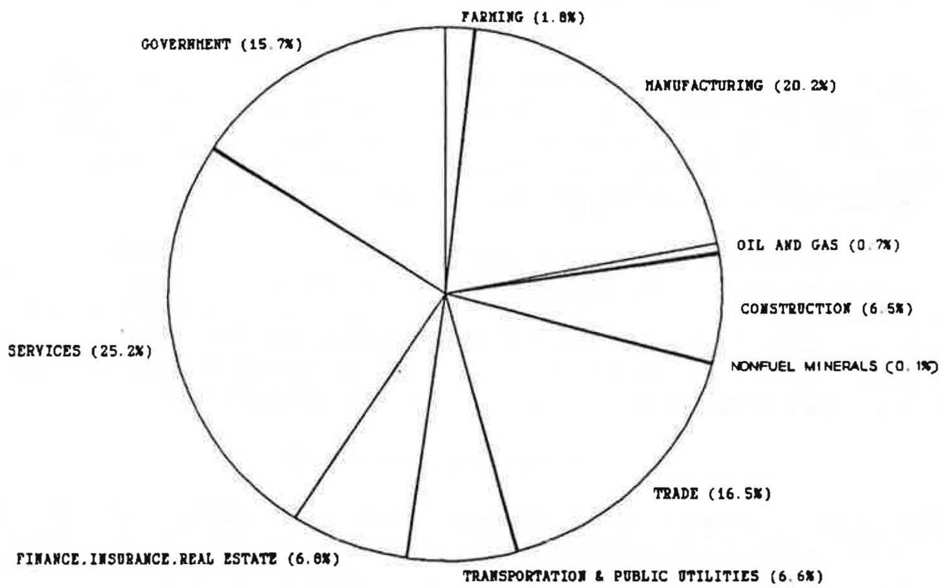
The California Desert Conservation Area, also referred to in this paper as the California Desert, consists of 25 million acres in southeastern California. This unit was established by the Federal Land Policy and Management Act of 1976 (FLPMA). The Act instructed the Bureau of Land Management (BLM) to study land allocation alternatives aimed at maintaining the pristine quality of the desert while minimizing conflicts over possible multiple uses of the land. Added to this

challenge are the mixed ownership patterns in the region. Although much of the land in the CDCA is under state or federal control, about one-half of the land in the California Desert is privately owned.

Just recently, Senator Alan Cranston of California reintroduced the California Desert Protection Act (S. 11) and Congressman Mel Levine submitted the House version of the same legislation. This bill seeks to classify approximately 7.5 million acres of the CDCA as national park or wilderness areas, preserving scenic and roadless lands in their current state.

III. The Minerals Industry in California and the CDCA

Mining does not play a major role in the economy of California. In 1985, only 0.07 percent of the state's labor force was employed in the production and processing of nonfuel minerals. This means approximately 8,800 people out of a total labor force of 12,937,000 were engaged in nonfuel mining-related activities (Data derived from U.S. Bureau of Mines, 1985, *Minerals Yearbook*, Volume 2, p. 91). As depicted in Figure 1, total industry earnings derived from nonfuel mineral production in 1985 amounted to about $350 million, or 0.1 percent of the $312,761 million generated by all industries in California (Data derived from U.S. Bureau of Mines, 1985, *Minerals Yearbook*, Volume 2, p. 93).



Source: U.S. Bureau of Mines, 1985, Minerals Yearbook.

Figure 1- Sources of Industry Earnings by Sector in California, 1985

In 1986, total sales by the nonfuel mineral industries in California amounted to $2.3 billion. However, nearly half -- $1.1 billion -- of these nonfuel mineral revenues were derived from the California Desert (BLM, 1987, The California Desert: Its Mineral Wealth and Potential, p. 2). Mineral output from the desert reportedly included 100 percent of domestic borates production, 97 percent of the country's rare earth minerals, 15 percent of the talc, 10 percent of the gypsum, and 6 percent of the metallic minerals production (BLM, 1987, The California Desert: Its Mineral Wealth and Potential, p. 2). Thus, while nonfuel mining represents a very small component of California's income and employment, mineral production from the California Desert represents a large proportion of total state output.

More than $400 million worth of minerals produced from the desert in 1985 was derived from borate production (U.S. Bureau of Mines, 1985, *Minerals Yearbook*, Volume 2, p. 91). The bulk of borate output is produced from two localities located on private land outside of the proposed protected areas in the CDCA. Most of the remaining $700 million of mineral output in the desert was obtained from production of other industrial materials, including large tonnages of relatively low value commodities such as sand and gravel, clays, gypsum, talc, and portland cement. In fact, production of industrial minerals accounted for more than 95 percent of the value of mineral output in the state of California (Data derived from U.S. Bureau of Mines, *Minerals Yearbook*, 1985, Volume 2, p. 91). (See Figure 2)

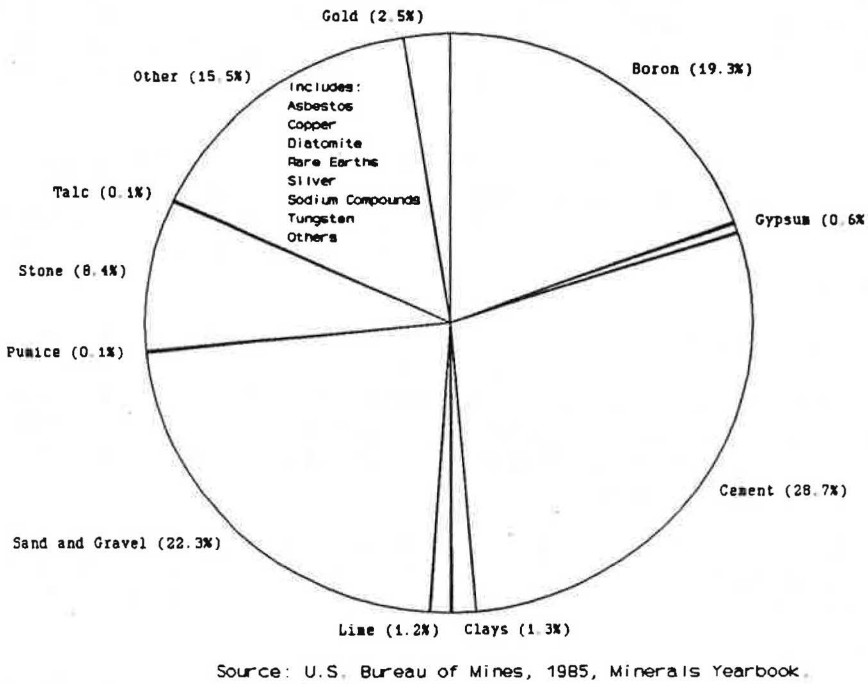


Figure 2- Value of Mineral Production in California, 1985

The most valuable metallic minerals produced from the CDCA are gold and rare earth metals[1]. About $115 million of gold and $30 million of rare earths were produced from the California Desert in 1987 and 1986 respectively (Data derived from Metals Economics Group, 1987, *A Study of Active U.S. Gold Mines* and U.S. Bureau of Mines, 1987, *Mineral Commodity Summaries*). All rare earths were produced from a single mine located outside the proposed Mojave National Park and the Wilderness Study Area in the Clark Mountains. Eight sites in the CDCA reported production totalling about 250,000 ounces of gold in 1987 (Metals Economics Group, 1987, *A Study of Active U.S. Gold Mines*).

[1]Rare earth metals contain elements 57 through 71 on the periodic table of elements, including elements lanthanum, europium, lutetium, and other lesser-known elements. Specialty applications for iron and steelmaking, petroleum refining, and glassmaking are the major uses for the rare earths (see Goerold, 1988).

IV. Public Lands, Mining Claims, and the Mining Law of 1872

Metallic commodities produced from federal lands in the California Desert are mined by companies holding mining claims. Firms obtain exclusive rights to most metallic minerals on federal lands by showing proof of discovery of a valuable deposit. The mining companies then must perform the equivalent of at least $100 worth of work on each claim per year to continue to hold exclusive rights to the minerals.

The current legal framework for mining claims dates back to the Mining Law of 1872. The primary purpose of this law was to encourage the exploration and economic development of the federal lands in the West. In 1872, the federal government assumed that the highest and best use of the large acreage of the empty public lands in the West was for the mining of mineral commodities. Since that time, although the basic requirements for filing mining claims have not altered, the population of the U.S. and California has multiplied greatly and the demands placed on the federal lands have changed.

Claimholders who have shown proof of discovery of a valuable mineral deposit hold what is known as valid existing rights. These rights supersede later actions that might affect land use. Thus, even if a claimholder controls land in the middle of an area that may later be classified as a wilderness or park area, the claimant continues to hold the rights of access and production of the minerals on the valid claim.

All current mineral producers on federal land in the California Desert hold valid existing rights and therefore have the legal protection from changes in land status. Claimholders in the California Desert that are not currently producing minerals may still hold valid existing rights if they can prove that they have found a mineral discovery of value. However, if the claimholders cannot prove a discovery following reclassification of federal lands in the California Desert, they would be forced to relinquish their claims.

The net result of the California Desert Protection Act on federal lands in the CDCA would be that individuals or firms with proof of valid claims will continue to have the rights to minerals on those claims. Claimholders who can not show the presence of valuable minerals must give up their claims.

V. Strategic and Critical Materials and the California Desert

The Bureau of Land Management reports that the California Desert contains 24 strategic and 3 critical materials (BLM, 1987, The California Desert: Its Mineral Wealth and Potential, p. 3). According to the BLM analysis, strategic materials are essential for national defense and critical materials are essential to the needs of the United States.

There is no single definitive source that describes which materials are strategic or critical. The reference that is possibly used in the BLM report cited above mentions at least 42 items that are important to national defense and industry (Federal Emergency Management Agency, 1986, *Stockpile Report to Congress, October 1985 - March 1986*, pp. 54-55). However, the majority of these materials are produced within the United States or are obtained from a stable and low-cost supply from other countries. As stated in an Office of Technology Assessment (OTA) report on strategic materials, "[T]he Nation should seek materials wherever they may be found, at the least cost and consistent with national security and the welfare of friendly nations." (OTA, 1985, *Strategic Materials: Technologies to Reduce U.S. Import Vulnerability*, p. 45). This agency's analysis asserts that materials obtainable at low cost from secure foreign suppliers are preferable to domestically-mined materials acquired at many times the cost of the foreign materials.

Using the above criteria, OTA maintains that there are actually only 14 strategic materials. According to the OTA evaluation, a material's strategic attributes are based on the critical nature of its uses and the vulnerability of its supply. Data covering 86 nonfuel materials from the U.S. Bureau

of Mines allowed the OTA to eliminate from strategic status all materials in which the U.S. is a net exporter. Two other criteria used to eliminate materials from strategic designation are materials for which the U.S. relies on Canada and commodities that have a high degree of geographical and political diversity in their production.

The list of strategic materials that resulted from the OTA analysis is divided into two tiers, as shown in Table 1. The first tier represents the materials that satisfied all of the criteria listed below for defining a strategic material.

"[The materials in the first tier] clearly met all of [these] criteria...

1). They are essential for the national defense and other important industries.

2). For some of their essential uses no satisfactory substitutes are available.

3). There is little or no production of any of these materials in the United States (although for some, recycling is significant).

4). They are supplied largely by a very few countries in a politically unsettled region (central and southern Africa), and this same region, plus the Soviet Union, holds most of the world's known resources."
(OTA, 1985, *Strategic Materials: Technologies to Reduce U.S. Import Vulnerability*, p. 52).

The materials in the OTA's second tier of importance met some but not all of the above criteria.

TABLE 1- Strategic Materials Identified by the Office of Technology Assessment

First Tier	Second Tier
chromium	bauxite/alumina
cobalt	beryllium
manganese	columbium
platinum group metals	diamond (industrial)
	graphite (natural)
	rutile
	tantalum
	tin
	titanium sponge
	vanadium

Source: Office of Technology Assessment, 1985, *Strategic Materials: Technologies to Reduce U.S. Import Vulnerability*, p 52.

None of the first or second tier strategic materials are currently produced or have reserves (economically producible deposits) in the 25 million acre-California Desert Conservation Area. Prior to 1945, 48,000 pounds of tin was produced from one mine in the CDCA, outside of proposed new park and wilderness areas (BLM, 1982, *California Desert Conservation Area Final Environmental Impact Statement and Plan: Appendix XIV Geology-Energy-Minerals*, p. 111). In addition, a small quantity of manganese was produced from the CDCA, largely outside of proposed new park and wilderness areas, apparently under subsidies administered by the federal government during World War II (BLM, 1982, *California Desert Conservation Area Final Environmental Impact Statement and Plan: Appendix XIV Geology-Energy-Minerals*, p. 100). The U.S. Bureau of Mines notes that the

National Research Council concluded "...[domestic land-based resources of manganese] should not be developed except in a dire emergency." (reported in U.S. Bureau of Mines, 1985, *Mineral Facts and Problems*, p. 486). They report that in an emergency situation the two best deposits for development are located in the Cuyanuna Range of Minnesota and in Aroostook County, Maine.

VI. Mineral Production Potential of the California Desert

A common argument forwarded by mining interests in discussing the mineral endowment of the California Desert is that "absence of evidence is not evidence of absence." According to this dictum, even though there may be no indications of potential mineralization in a region, some valuable materials may be discovered for exploitation in the future.

This argument concludes that public lands should be left open to speculative future mineral production even at the expense of known wilderness, wildlife and other values. Such a policy would implicitly assume that mining -- even in areas with unknown potential -- is the highest and best use of the land. As discussed in section III, mining may have been the highest and best use in 1872 when the Mining Law was enacted. At the present time, however, the value of the wildlife, wilderness, and recreation attributes of the public lands may outweigh the benefits of mineral production.

The mining industry's argument is not totally without merit. New technologies may be found that can identify and extract minerals at lower costs, or new deposits may be discovered that have been overlooked by previous mineral exploration. However, criteria must be established to determine areas with the greatest potential for future mineral production.

An examination of currently operating and proposed new mines reveals what criteria are likely to be used to find future mines. The commodity of greatest interest to most metallic mining companies over the past 20 years has been gold. Most new gold mines are not located in areas that have never been mined. In fact, one of the foremost indicators of mineral potential is the presence of historical mining activity. There are 30 active and proposed gold mines in California, 14 of which are located in the California Desert (Data derived from Metals Economics Group, 1987, *A Study of Active U.S. Gold Mines* and *Potential New U.S. Precious Metal Production*). Twenty-seven of the 30 mines in California and 12 of the 14 mines in the California Desert are located on the sites of old mining districts.

The significance of new gold mines located at historical mining sites is that the mineral potential of the California Desert can be assessed with greater confidence when these historical mining sites are identified. The California Desert Protection Act has drawn wilderness boundaries to exclude areas with historical mining activity where feasible. This legislation recognizes the fact that it is likely that future mining activity will take place in areas that have already been mined in the past. Although no one can say with certainty that a particular site will never be mined, the exclusion of most historical mining areas from wilderness areas should minimize likely future mineral conflicts.

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TECTONICS OF THE SOUTHERN CALIFORNIA DESERT AS INTERPRETED FROM GRAVITY AND MAGNETIC DATA

O'Brien, D.P., Puckett, J.P., Seifert, D. and Austin, W.H.

ABSTRACT

A compilation of publicly available gravity and magnetic data has been completed for portions of the high desert region of southern California. The compilation encompasses the eastern front of the Sierra Nevada Mountains: Indian Wells Valley, Salt Wells Valley, and Coso Basin; the Argus Range and El Paso Mountains; Searles Valley; the Slate Range; Panamint Valley; and the west edge of the Panamint Range.

Older traditional literature references have interpreted this area as having a simple geology comprised of northerly-trending horst and graben bounded mountains and valleys as was typical for the Basin and Range Province. Recent investigations have increasingly pointed to a complex history of thrust faulting as the major mechanism shaping the present day physiography and the underlying geologic structures.

A recent article about an area on the west side of the southern San Joaquin Valley, discusses a mechanism for accommodating the stresses which are perpendicular to the San Andreas Fault, by deep-rooted detachment in the transition zone from brittle to ductile rock in the midcrust at about 15 km below sea level. Such a mechanism has important implications for both this study area and the entire allocthonous terrain of western North America. Recent drilling in Cajon Pass has been justified on the basis of testing the validity of this same mechanism.

Our three dimensional gravity modeling of the compiled data suggests that a complex tectonic model also is appropriate for the study area. The important geologic implications of this modeling are the evidence for 1) segments of oceanic crust on the east side of the Sierra Nevada Mountains and 2) widespread thrust faulting. Further corroborative evidence is provided by the aeromagnetic data.

FOLDING OF THE BARSTOW FORMATION IN THE SOUTHERN CALICO MOUNTAINS, SAN BERNARDINO COUNTY, CALIFORNIA

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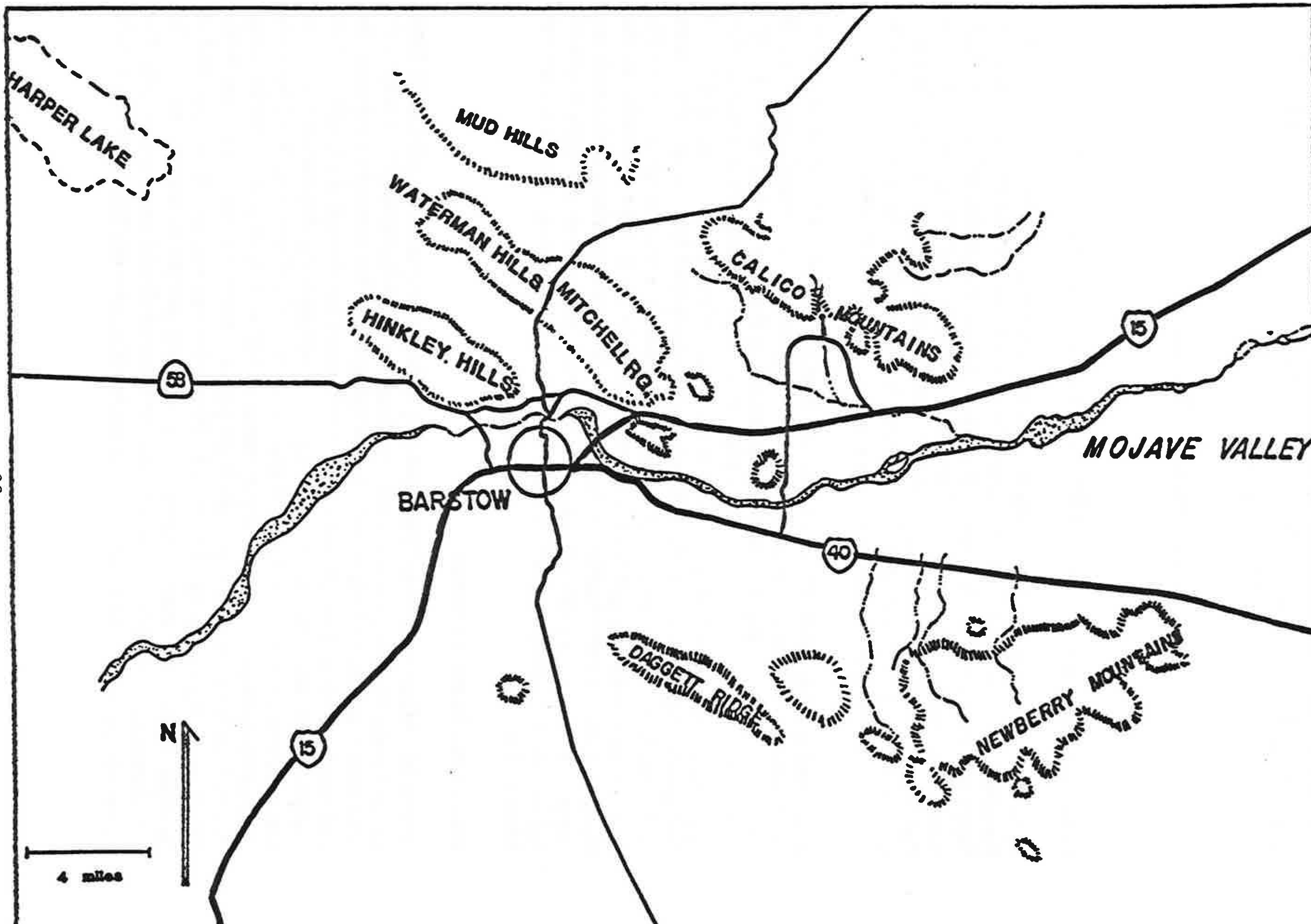
ABSTRACT: Well developed folding in the sedimentary strata of the middle Miocene Barstow Formation occurs along the south flank of the Calico Mountains northeast of Barstow, California. The folds lie within an eastward widening wedge of Barstow which is generally, but not always, in gradational contact with the underlying lower Miocene Pickhandle volcanics. The wedge of Barstow is bounded on the south by the Calico fault and on the north by the Pickhandle volcanics. It pinches off to the west near a point where the strike of the Calico fault swings conspicuously to the north.

In at least one site, near the west end of the wedge, evidence in the form of missing basal Barstow redbeds, present to the east along strike, and limited exposures of low-angle, south-dipping polished planes separating Barstow from Pickhandle, supports a slump origin for some of the folds. Elsewhere, folding not associated with apparent decoupling of the Barstow from the Pickhandle affects the major portion of the Barstow in the southern Calico Mountains. Sub-horizontal fold axes trend between N75E and N75W. The dips of axial surfaces range mainly from near vertical to steeply south- rarely north. The geometry and attitude folds in the Barstow Formation in the study area and the easterly strike of the normally northwesterly striking Calico fault are suggestive of a transpressive environment which may be related to a recently proposed regional east-west trending belt of north-south shortening passing through the central Mojave block.

Nature of the Barstow Formation

The middle Miocene Barstow Formation (Fig. 6) in the study area along the south flank of the Calico Mountains consists mainly of basin center lacustrine pelites and sands with minor non-clastic beds complexly intercalated with basin margin fanglomerates and fluvial sands and conglomerates . A tuffaceous component is present in most samples taken from any part of the Formation. Load casts and dessication crack casts are commonly observed in the finer grained units of the Formation. Sand beds are frequently cross-stratified and display scour and fill structures and graded bedding. Several tuff beds up to a meter thick are present in the Barstow Formation in the Mudhills to the northwest (Fig. 1). The Formation can commonly be observed to become significantly coarser upward, grading from pelites to boulder and cobble conglomerates, probably reflecting the progradation of alluvial fans into the basin. The larger clasts consist mainly of dacite to andesite with occasional fragments of granitoid



Locality map Barstow area

Figure 1

rock. The feldspars in these granitoid clasts, in most cases, are completely altered to clay. Individual beds can rarely be followed more than kilometer along strike and because of this, stratigraphic generalizations are difficult to apply to the Formation.

In the area near the old town of Calico and for a mile or so to the east the basal units of the Barstow are redbeds in gradational contact with the underlying Pickhandle Volcanics. To the west, between the Waterloo and Langtry deposits (Fig. 7), the Barstow is in fault contact -the Calico Fault- with the volcanic rocks. At the northwest end of the Calico Mountains, northeast of the Calico Fault, the Barstow rests unconformably upon the Pickhandle Formation.

Within the Waterloo and Langtry deposits which lie adjacent to the Calico Fault a few kilometers northwest of the old town of Calico and Wall Street Canyon the pelites of the lower Barstow are extensively silicified. The silicification may have been one of the processes attendant to the establishment of a very shallow hydrothermal system responsible for the calcite-barite-silver-gold mineralization in the district (Fletcher, 1986 and Jessey,1988). The mineralization may have been concurrent with active subsidence and filling of the Barstow basin and taken place at depths in the sediment of less than 100 meters (Fletcher,1986).

Initiation of the sedimentation in the Barstow basin began possibly in very latest early Miocene (Burke et al, 1982), however. the bulk of the Formation, is middle Miocene. The boundaries of the basin may have lain somewhat west of the Gravel Hills, fifteen to twenty kilometers northwest of Barstow, to the area around the Alvord Mountains, forty to fifty kilometers east of Barstow. Link (1980) tentatively suggests an extension of a branch of the Barstow Basin into the Kramer Junction area.

Folding in the Barstow Formation

Lindgren (1887) was the first to mention the folding of the Barstow Formation. Since then it has been studied by Weber (1976, 1980), Dibblee (1970), Fletcher (1986) and Paine and Glass (1987). The Barstow Formation, in many exposures in the study area in the southern and southeastern Calico Mountains, can be observed to have undergone extensive folding. The folding of the Formation is not restricted to this area but elsewhere the style, scale and geometry of the folds are different from those in the area described here. The body of folded Barstow strata forms a large, east-opening wedge which lies along the southern flanks of the Calico Mountains tucked between the Pickhandle Volcanics to the north and the Calico Fault on the south. To the east, beyond the mouth of Mule Canyon, this pattern is modified by the presence of younger dacitic to andesitic plugs some of which lie between the Calico Fault to the south and the Barstow to the north. The insertion of these plugs appears not to cause other than local deformation of the Barstow. The geometry and orientation of the folds adjacent to the volcanics are little different from that where the young volcanics are absent.

The folds in the southern Calicos have amplitudes ranging from less than a meter to several tens of meters (Fig. 3 and 4). Familiar to central Mojave geologists are well

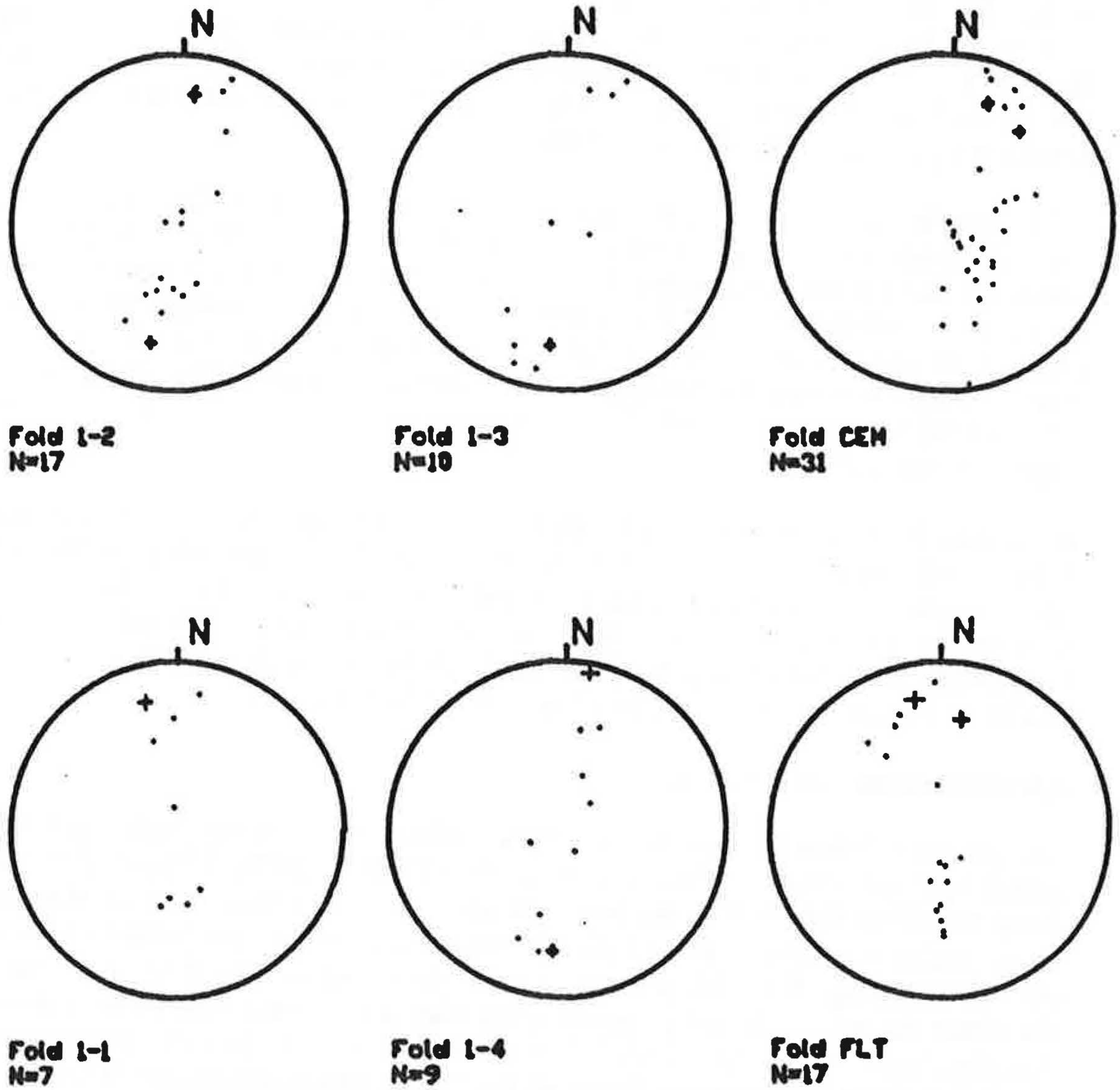


Figure 2a - Lower hemisphere, Schmidt net projections poles to bedding in folds near Wall Street Canyon - + are poles to measured axial surfaces

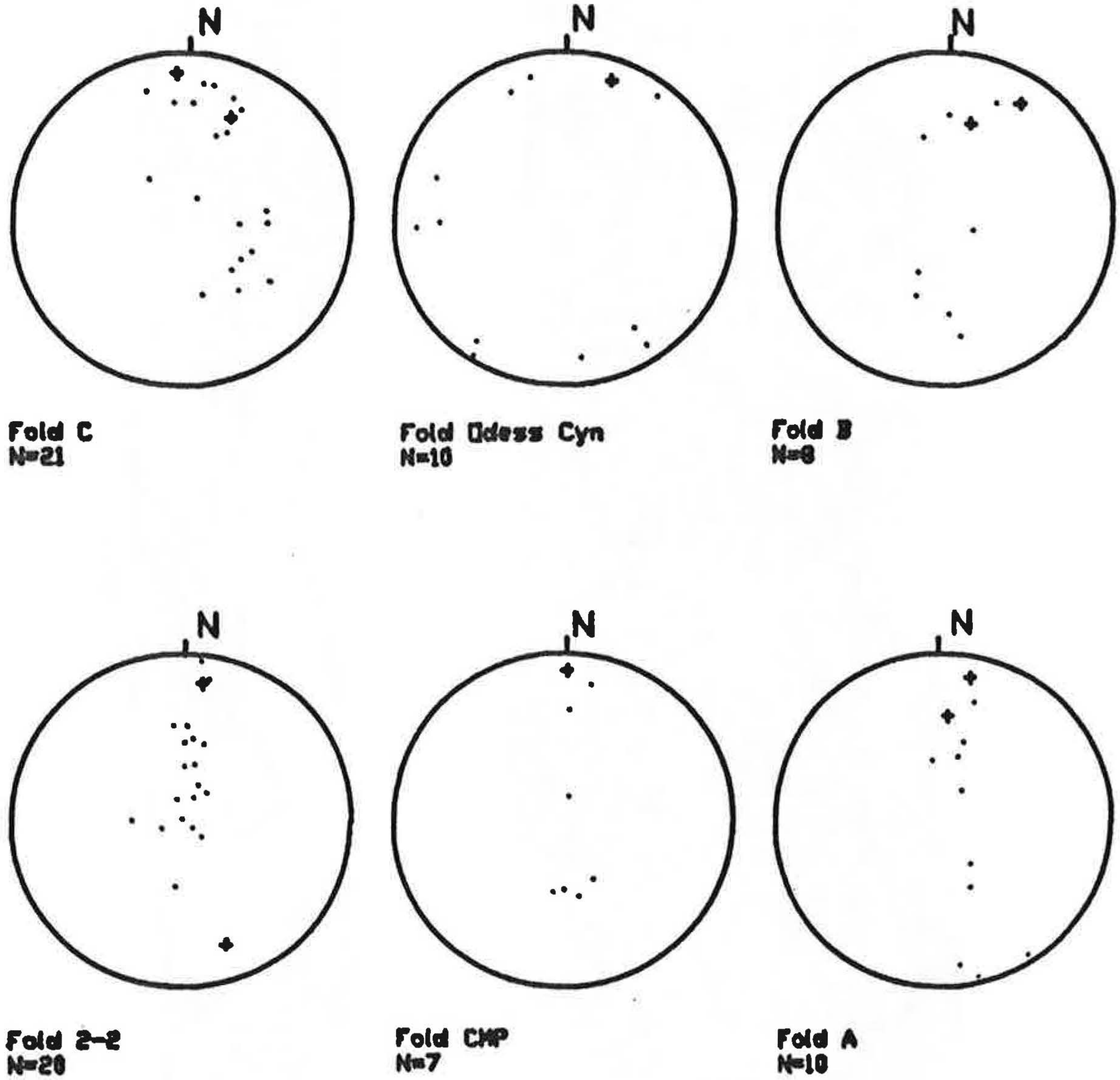


Figure 2b - Lower hemisphere, Schmidt net projections poles to bedding in folds near Mule Canyon - + are poles to measured axial surfaces

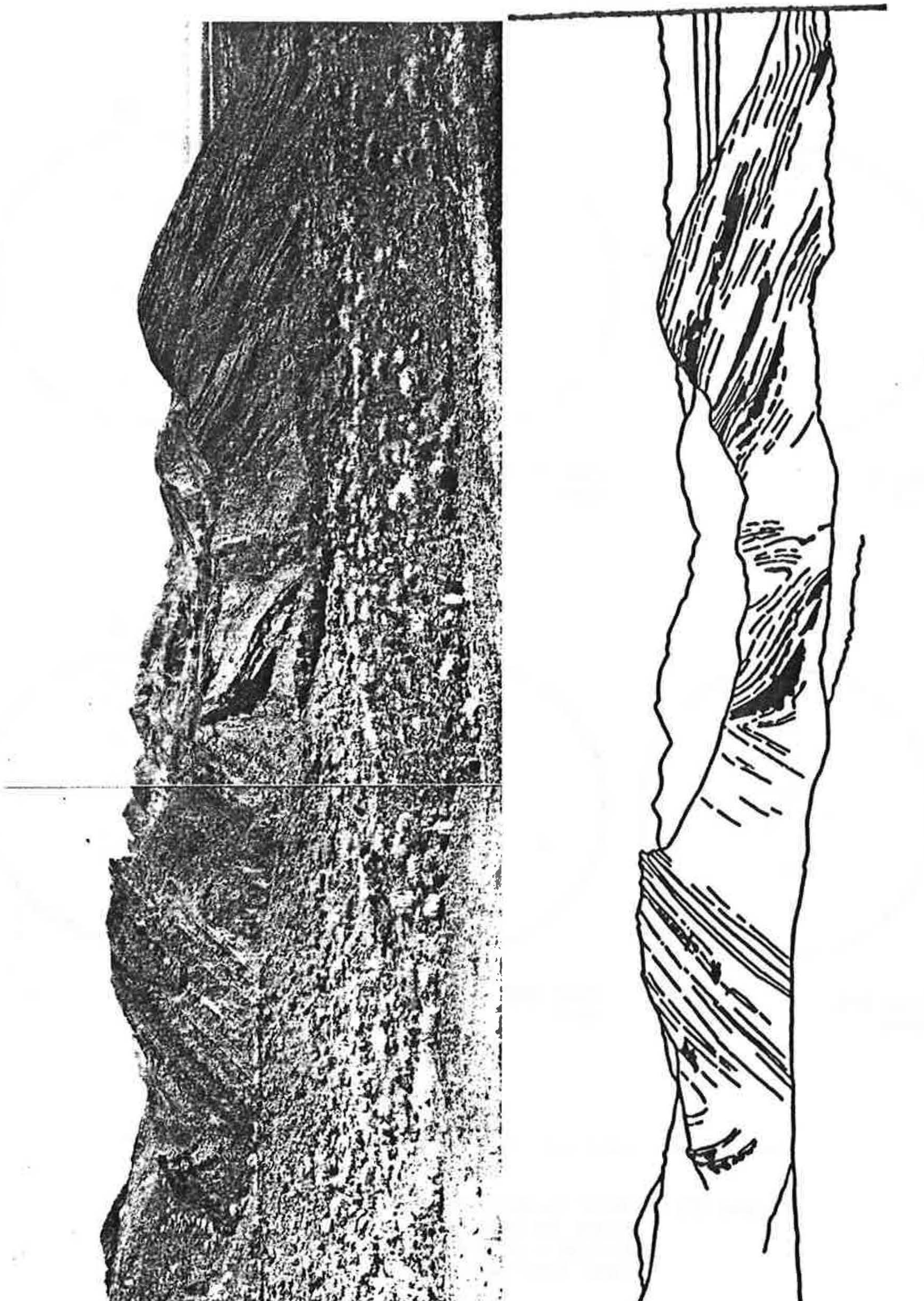


Figure 3 - Typical folding style in Barstow Formation in Calico Mtns.

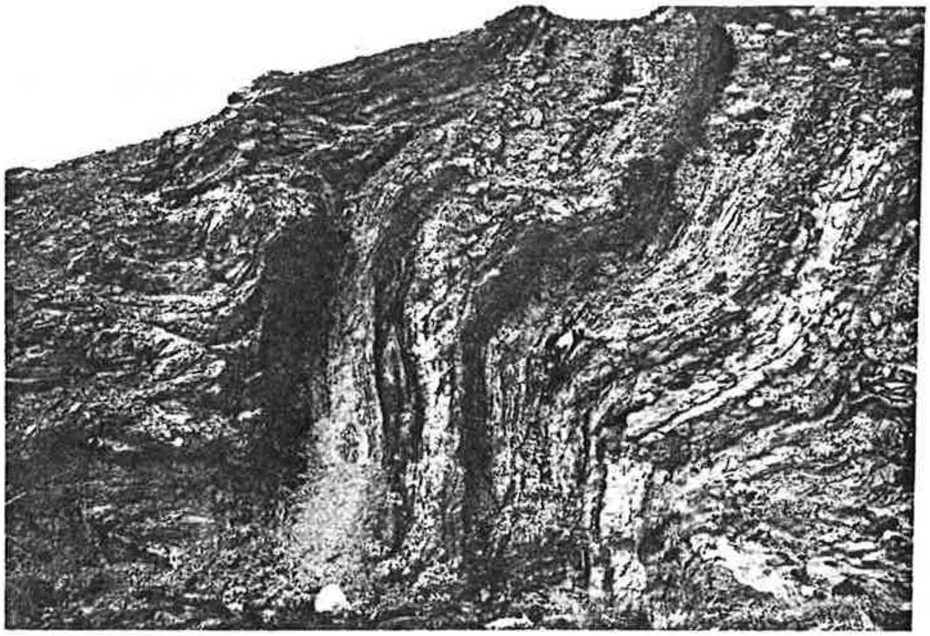


Figure 4a Folds in the Barstow Fm. (geologist-scale)

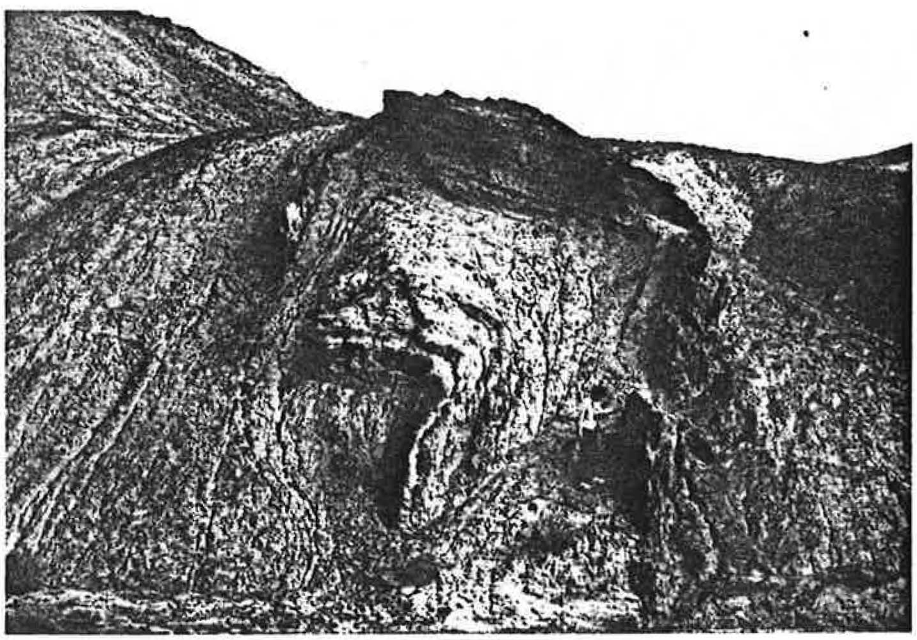


Figure 4b Folds in the Barstow Fm. in Mule Canyon

exposed and easily accessible examples of these folds in the parking lot at the now commercialized ghost town of Calico. The larger folds can be traced continually along strike for hundreds of meters. The amplitude and style of folding does not vary significantly perpendicular to strike. Many have sub-vertical axial surfaces and sub-horizontal axes. The trend of the axes is generally east to east-southeast. (Fig. 2a and 2b). Several folds exhibit south dipping axial surfaces. Most of the folds fall into Ramsay's class 1A or 1B and reflect flexural-slip folding mechanisms.

Fletcher (1986) identified a significant thrust fault affecting the Waterloo deposit at the west end of the wedge of Barstow described above. The fault dips at a low angle to the northeast and occurs in the area where the strike of the Calico fault swings from easterly to northwesterly.

Weber (1976, 1980) suggested that the folding in the southern Calicos resulted from gravitational movement of sheets of Barstow off positions above the Pickandle Volcanics in response to up-bowing after shallow intrusive activity. Present work supports, in part, Weber's contention. West of Wall Street- the canyon in which the old town of Calico is located- some of the folds appear to be rootless, that is, the base of the folded blocks is defined by a planar discontinuity. These planes, in the few places where they are exposed, are smooth and faintly striated. Missing stratigraphic intervals, the most

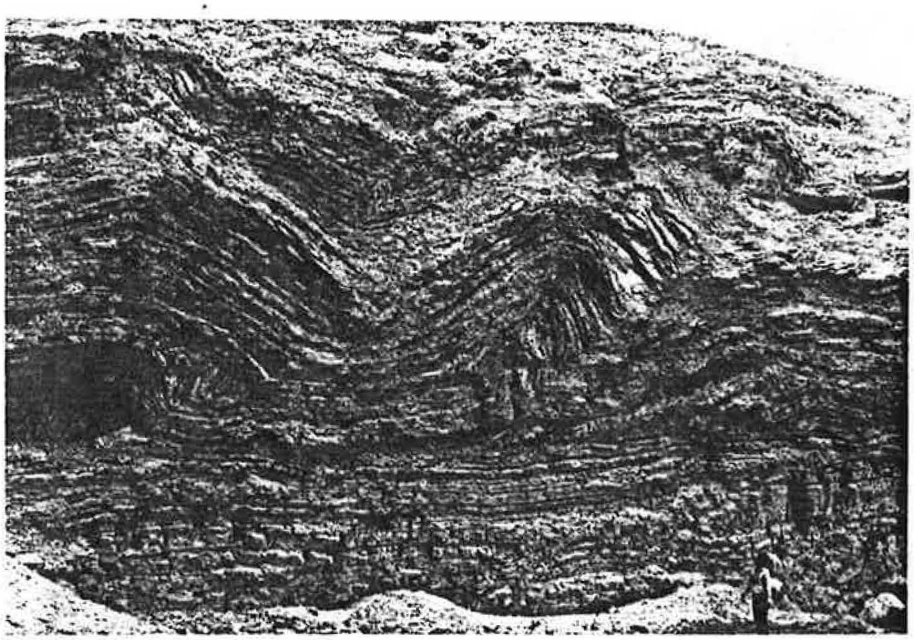


Fig. 5 Folds produced by slumping in the Barstow Formation

STRATIGRAPHIC SECTION

Calico Mountains

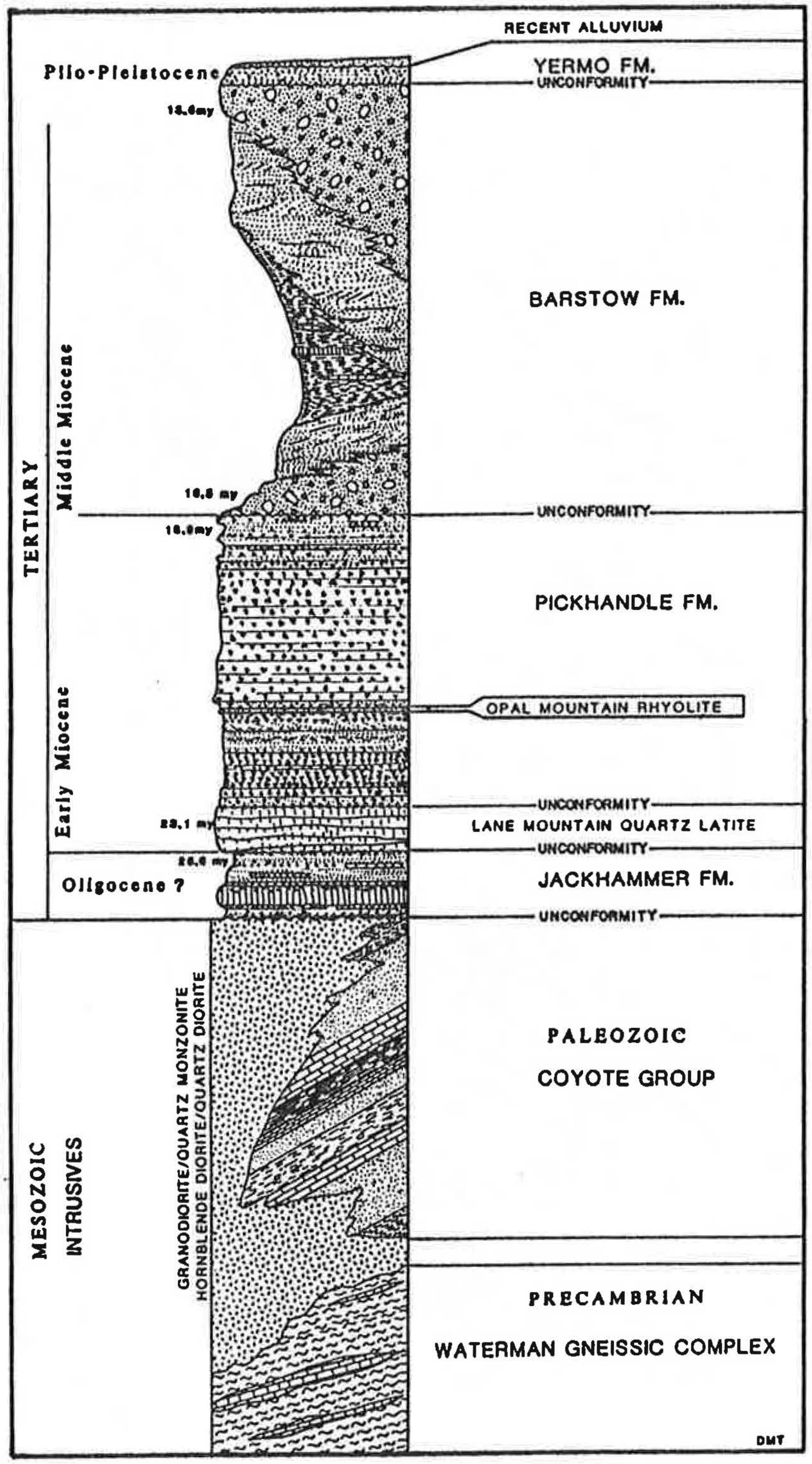


Figure 6

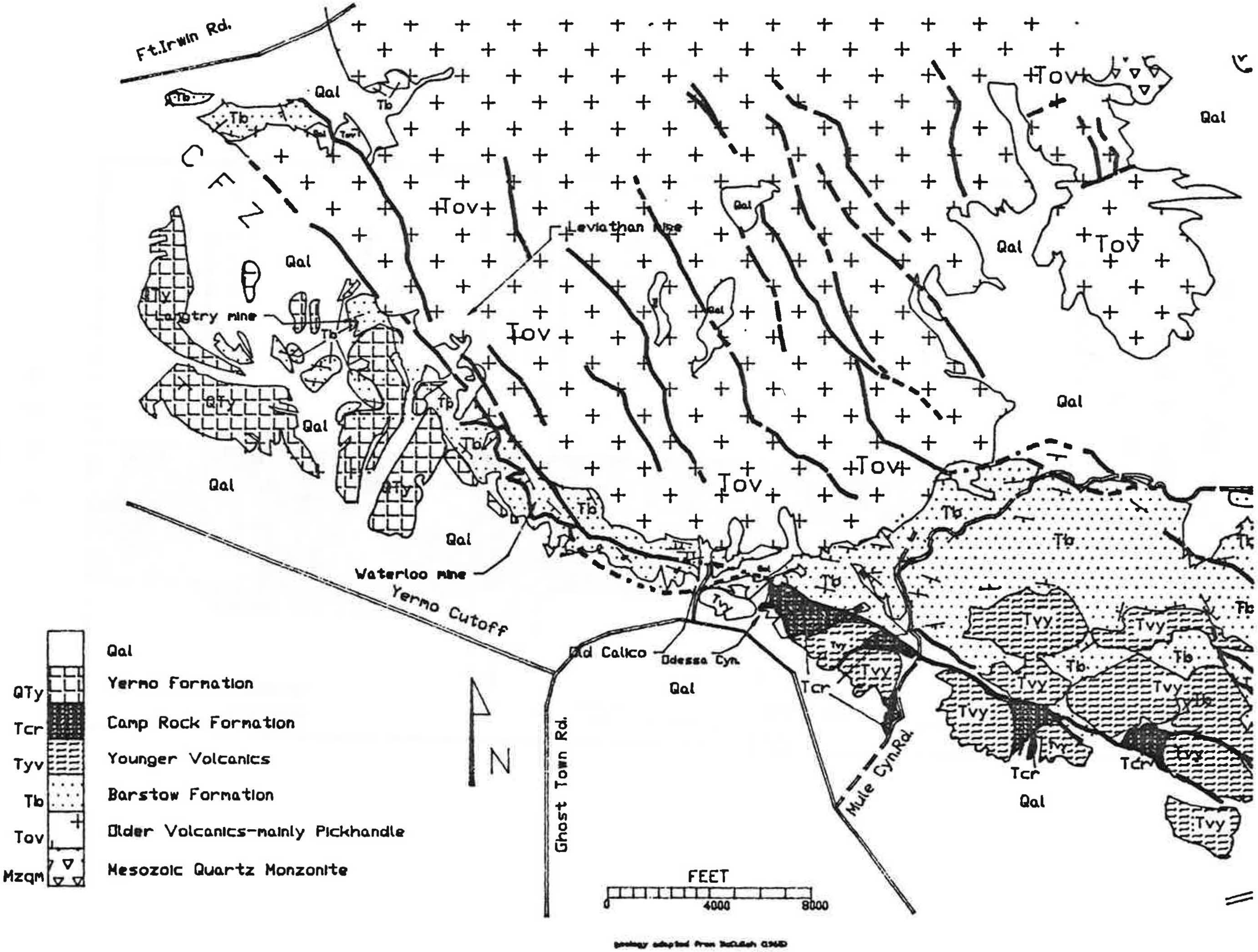

Ft.Irwin Rd.
CFZ
Tov
Qal
Tb
QTy
Langtry mine
Leviathan Mine
Waterloo mine
Yermo Cutoff
Old Calico
Odessa Cyn.
Tcr
Tvy
Ghost Town Rd.
Mule Cyn.Rd.
N
FEET
0
4000
8000
Qal
QTy
Yermo Formation
Tcr
Camp Rock Formation
Tyv
Younger Volcanics
Tb
Barstow Formation
Tov
Older Volcanics-mainly Pickhandle
Mzqm
Mesozoic Quartz Monzonite

Figure 7

obvious being the redbeds present at the base of the Barstow east of Wall Street Canyon, inferred here to have been cut out during slumping, add support to the hypothesized localized cascade folding.

Paine and Glass (1987) relate the folding in the Barstow Formation to compression associated with a major bend in the Calico fault as did Dibblee (1967). In his discussion Dibblee notes that the intensity of folding increases with proximity to adjacent faults. The concept of a transpressive origin for the folds is not new.

Dokka (1987), in analyzing the net slip on the dextral faults of the Mojave, discovered what he believes is an east-west line passing through the area of Barstow defining a zone of convergence separating the northwest striking Mojave right-slip faults into a northern and a southern domain whose net cumulative slips are discordant, that is faults in the northern domain exhibit smaller net slip than do their southern extensions. As such the line represents a zone of concentrated north-south shortening which may be related to a heretofore unrecognized structural dislocation responsible for disrupting the northwest directed distributive stain system of the Mojave.

Southward slump of blocks of Barstow off the Pickhandle volcanics should have produced folds with axial surfaces dipping generally to the north, away from the direction of transport (De Sitter, 1964). At the very least the trend of fold axes along the front of the range should swing irregularly reflecting the general geometry of the range front. More realistically, large variations in trend of the fold axes reflecting variations in the distances and rates of transport of various portions of the slump blocks which in turn were caused by impediments to forward movement, should be observed. Structurally incompetent units act as horizons of dislocation and are thus usually missing or extremely attenuated in slumped blocks (De Sitter, 1964). Figure 5 shows typical fold geometries resulting from slump . Translation has occurred on single horizons causing only selected units to undergo folding. Folds are disharmonic and with folding intensity appearing to culminate in areas where resistance to forward movement causes a buttressing effect. Axial surfaces dip away from transport direction.

In conclusion the data gathered during recent work in south part of the Calico Mountains support, with some exceptions mentioned above, a compressional- perhaps transpressional- origin for the folds. The consistent orientation of the fold axes, the presence of at least one significant thrust fault, the vertical to south dip of the axial surfaces and the presence of a normal stratigraphic succession in the folded Barstow are all inconsistent with slumping and supportive of north-south compression.

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Chapter 3

PRECIOUS METALS EXPLORATION AND DEVELOPMENT

ORE PETROGENESIS AT THE HART GOLD DISTRICT, CASTLE MOUNTAINS, SAN BERNADINO CO., CALIFORNIA

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INTRODUCTION

The Hart Gold District

Gold was discovered at the Hart district in 1907, with vigorous mining activity during 1908 and 1909. The three mines with known, although unrecorded, production during the period 1907 to 1913 are the Orobelle mine (the most active of the three), the Hart Consolidated mine (actually a group of small adits and a major haulage tunnel), and the Big Chief mine (Hewett, 1956). Other mines in the district with unrecorded production during the 1920's and 1930's are the Jumbo mine, the Valley View mine, and the Chief of the Hill mine (Fig. 2). The Valley View mine was the site of the most recent activity in the district. Reportedly, the highest average grade as well as the majority of the ore mined in the district came from the 200 foot level foot the Valley View. A small mill was constructed on the site and ore from other local districts as well as from other mines at Hart was reportedly milled here. Three roughly parallel northeast striking vein systems were exploited by the Hart group of mines. The largest and most productive of the vein systems is the Orobelle, Jumbo. Valley View, and the Big Chief trend (listed from northeast to southwest along the strike of the vein system;Figure 1). The Hart Consolidated group is located on the next vein system to the east of the Orobelle vein. The Chief of the Hill is. in turn, located on a small vein system east of the Hart Consolidated vein system.

From the 1960's until 1984, hydrothermally altered volcanic rocks associated with the mineralized and silicified zones were mined for clay from a pit on the former location of the Big Chief Mine and a smaller pit located just west of the Orobelle Mine.

Epithermal Gold Systems

It is generally accepted that volcanic-hosted. high level epithermal deposits form from circulating meteoric waters. This conclusion is based primarily on oxygen and hydrogen isotope data (Taylor, 1974). The majority of these data are apparently derived from bulk vein and altered host rock samples, as no mention is made of efforts to define differences in the isotopic composition of early versus late fluids in these systems. O'Neil and Silberman (1974) suggest that magmatic fluids play a role in the development of the Comstock lode deposit, and possibly other epithermal deposits. They state further that dominant meteoric water values may represent a sampling bias toward more accessible, later stage mineralization.

Some recent, detailed oxygen and hydrogen isotope studies of vein and breccia deposits which formed at moderate to deep levels show a significant magmatic fluid component to the hydrothermal fluids. An example is the Golden Sunlight breccia pipe deposit in Montana (Porter and Ripley, 1985). Viglino et al. (1985) on the basis of oxygen and hydrogen isotope evidence suggest a major magmatic component in fumarole condensates from the Augustine volcano, Cook Inlet, Alaska. Barnes (1984) suggests that a significant component of the steam at Mount St. Helens is derived from a metamorphic brine in underlying meta-andesites.

There is a close spatial and temporal relationship between mineralization and the late shallow rhyolite intrusive rocks at the Hart district. Therefore, a genetic relationship, beyond that of merely the heat source, may exist at Hart. Fluid inclusion, strontium isotope, and oxygen-hydrogen isotope studies were conducted on mineralized vein samples from the Hart district. Results from these studies suggest that a genetic relationship between gold mineralization and the intrusive rhyolites and their associated magmatic system does appear to exist at Hart.

GEOLOGY

The Hart district is hosted by approximately 1000 m of folded and faulted, intercalated Tertiary volcanic and sedimentary rocks which rest on Precambrian mafic and felsic, high grade gneissic and granitic basement rocks. The volcanic rocks include bedded pyroclastic, lava flow, and hypabyssal rocks, and associated debris flows of silicic and intermediate composition, as well as less abundant mafic rocks. The sedimentary rocks are fine to coarse grained and are primarily epiclastic-volcanoclastic. A conglomeratic unit containing Precambrian basement, Paleozoic carbonate. and Tertiary volcanic rock clasts occurs at the base of the bedded sequence. This sequence of bedded rocks is intruded by a complex of rhyolite intrusives and flows.

These rocks lie on the west limb of the northeast-trending Castle anticline. The east limb of the Castle anticline, in the Hart district, is a thinner section of silicic. intermediate, and mafic pyroclastic and lava flow volcanics, debris flows, and the basal conglomerate. These rocks extend south about 25 km along the east boundary of Lanfair Valley and form the Piute Range.

Lithic Units

Tertiary volcanism in the Castle Mountains and northwest Piute Range was sporadically active from roughly 18.0 my to 12.8 my. There is evidence that minor mafic volcanism as young as 8.0 my occurred at unspecified locales in the Piute Range (Nielson, 1987). The resulting volcanic pile is divided in this report into: (1) a 18.0 my to 14.0 my bedded sequence of predominately intermediate composition volcanic flow, intrusive. pyroclastic, and associated volcaniclastic sedimentary rocks (bedded sequence rocks), and (2) a rhyolite flow-dome complex (Castle Mountain rhyolite complex). Fig. 2 is a simplified geologic map of the Hart district.

Lower bedded sequence rocks correlate with Turners (1985) 18.0 my - 16.1 my sequence, and the upper bedded sequence rocks with his 16.1 my to 14.0 my sequence. Turner (1985) also provides a 12.8 million year age for the Castle Mountain rhyolite complex. Felsic to intermediate flows and flow breccias in the lower bedded sequence correlate temporally, although probably not in source, with regionally distributed Patsy Mine age rocks. The dominance of felsic and intermediate flow rocks in the lower bedded sequence suggests a local source.

The upper bedded sequence is dominated by felsic and intermediate pyroclastic, epiclastic, and intermediate hypabyssal rocks, and related debris flows. Lesser mafic flows and minor mafic intrusives are also part of this unit, having been erupted and emplaced late in the stratigraphic sequence. Presence of block- and cobble-size lithic fragments, and ash-flow tuff structures such as cross-bedding and reverse grading, and intercalated debris flows indicate a local eruptive source for at least some of the pyroclastic rocks. Upper bedded sequence hypabyssal intrusive and flow rocks are undoubtedly local in origin. It has been suggested (Bingler and Bonham, 1973 ; J. Neilson, pers. comm.) that the regionally distributed tuff of Bridge Springs may be present in the Castle Mountain volcanic pile. If so, it's 15 my age (Anderson and others, 1972) would make it part of the upper bedded sequence. The source for the tuff of Bridge Springs is unknown.

After an approximate 1.5 million year hiatus of volcanic activity subsequent to the eruption of the upper bedded unit rocks, rhyolite dikes, sills, and flow-domes of the Castle Mountain rhyolite complex were emplaced. These 12.8 my rhyolites are temporally coincident with the regionally distributed Mt. Davis age volcanics of Longwell (1963). Based on surface and underground mapping of intrusion contacts it has been determined that the conduits for the rhyolite magma are sets of deeply penetrating northeast trending fault and(or) fracture structures. It has been suggested by J. Neilson (pers. comm.) that the northeast trending rhyolite magma conduit structures were previously utilized as eruption fissure vents for the locally derived Castle Mountain volcanic rocks. Resurgent magmas, such as the Castle Mountain rhyolites, commonly employ previous eruption vents as intrusion conduits due to their deep crustal penetration to magma chamber levels. The northeast striking rhyolite dikes consistently dip steeply southeast to 50° southeast. Turner (1985) demonstrated, using stereonet protections of rhyolite flow banding planes, that rhyolite plugs of the Castle Mountain rhyolite complex have apparently been rotated from vertical during post-intrusion folding of the Castle anticline. Tilting is also demonstrated when one rotates the northwest dipping bedding planes (30° - 40° dips) of the west limb of the anticline back to an assumed pre-folding horizontal attitude. Coincidentally the southeast dipping rhyolite dikes (35° - 55° dips) are rotated to their assumed near vertical original attitudes.

The above observations suggest the following presumed sequence of events: (1) Movement of magma to shallow crustal levels. (2) Fracturing of country rock overlying the shallow magma chamber;

(3) Preferential penetration of NE trending fracture and(or) fault structures to near magma chamber levels. (4) Tapping of the magma chamber by these deep penetrating structures resulting in eruption of magma along these conduits. (5) Ongoing eruption of alternately felsic, intermediate, and magic rooks from 14 million to 18 million years ago along the northeast trending fissure eruption vents. Continued movement within and around the magma chamber ensured open conduits along this well established northeast trending zone of weakness, and allowing eruption of the basal and upper bedded units. No fissure vent area collapse (i.e. cratering) subsequent to the four million years of eruptive activity is documented. Because of a thickening of the bedded volcanic pile to the west (Figure 3) it is probable that the main eruption vent(s) of the locally derived basal and upper bedded units are located west of the fissure vents that localized the rhyolite dikes. The resurgent rhyolites utilized the eastern, probably later forming fissures. Interfingering of regionally derived volcanic rocks, such as patsy Mine volcanics and possibly the Tuff at Bridge Springs and the Peach Springs Tuff, would have been ongoing throughout the 14 my to 18 my time period. (6) Resurgent intrusion and eruption of rhyolite magmas and lavas along the same northeast trending fissure vents roughly 1.5 million years after cessesion of the previous eruption activity that was responsible for the basal and upper bedded volcanic units; (7) Initiation of folding and formation of the Castle anticline.

Hydrothermal activity in the Hart district was probably initiated during the late stages of event 6, and was ongoing during events 6 and 7.

Structure

The structure of the Castle Mountains is dominated by the broad. open. northeast-trending Castle anticline (Fig. 2). The Castle anticline gold axis trends N35°E and plunges approximately 3° to the southwest (Hewett, 1956). The Castle Mountains roughly define the west-limb of this asymmetrical anticline; the west limb dipping more steeply than the east limb (Fig. 2). The east-limb is comprised of Patsy Mine-age felsic to intermediate flows, shallow intrusive rocks, tuffaceous rocks, and debris flow volcanic rocks, all underlain by a fine to coarse grained basal conglomeratic sediment (composed of Precambrian basement, Paleozoic carbonate, and Tertiary volcanic clasts). The basal conglomerate becomes progressively finer grained to the east, away from the anticlinal axis. This sequence is capped by the basalt and(or) basaltic andesite flows and flow breccias of the northwest Piute Range.These mafic flows and flow-breccias are either part of the Patsy Mine-age volcanic sequence or younger Mt. Davis-age volcanics. This volcanic sequence also defines the northwest Piute Range. Bedded rocks of the basal and upper bedded units generally strike northeast and dip moderately northwest on the west-limb. The few exposed bedded rocks of the east-limb have shallow southeast dips in the Hart district (Fig. 2). Dips on the east-limb steepen to the north. eventually becoming as steep as those on the west-limb.

Precambrian basement rocks outcrop north of the Hart district along the floor of the valley between the Castle Mountains and the northwesternmost extension of the Piute Range, defining the core of the southwest plunging Castle anticline. The Tertiary-Precambrian contact forms a U-shaped map pattern that is characteristic of outcropping folds, Hewett (1956), Bingler and Bonham (1973), Turner (1985). Shallow southwest plunging continuity of the fold through the Hart district is apparent in Fig. 2. The inferred trace of the anticline axis is defined by a small valley between the east-flank of the Castle Mountains and the west-extension of the Piute Range across which bedding plane dips reverse.

A complex set of northeast trending (sub-axial planar), southeast to vertical dipping normal faults and fractures penetrate the rocks throughout the Hart district. These structures are consistent with the dominant structural and topographic grain of the Castle Mountain area, in particular the south and central sections. Various other structures, subordinate in extent and size to the dominant northeast trending structures, range in orientation from N65°-80°E, 40°-50°SE to N60°W, 80°-90°SW and intersect the dominant northeast-trending structures in places (Fig.2). The young rhyolite intrusive-flow complex followed a series of at least three and possibly five sub-parallel, northeast-trending, moderate southeast to sub-vertical dipping fault and fracture systems during intrusion in the Castle Mountains. Extensive rhyolite emplacement occurred along these structures in the southern Castle Mountain - Hart district area. Continued post-emplacement movement of the northeast fault-fracture system produced similarly oriented fault-fracture structures within crystallized rhyolite.

The later, subordinate northwest and northeast structures also cut the rhyolite. Zones of intersection of the dominant northeast structures with the subordinate northwest and northeast structures produce zones of increased fracture permeability, and may have further enhanced localization of the post eruptive rhyolite intrusive-flows. These structure-intersection zones of enhanced fracture permeability clearly localized hydrothermal ascent as geothermal fluid conduits and hot-spring vents (Fig. 2).

MINERALIZATION

Gold-mineralization at the Hart district is the modern manifestation of a geothermal system that was active roughly 12.4 my ago. Mineralization is spatially and temporally related to the waning stages of local Castle Mountain area volcanic activity. Twelve million years of exhumation has exposed the upper and middle levels of the paleohydrothermal system. Banded quartz veins, silicified hydrothermal vent breccias, peripheral stockwork quartz vein systems, and large areas of propyllitic and argillic alteration are exposed. Five parallel to sub-parallel, northeast striking, southeast to vertical dipping, roughly linear silicified vein and breccia structures are exposed at the surface over an area of approxinately 4 km. x 5 km. (Fig. 2). These vein and breccia structures mark the hydrothermal fluid conduits (fault-fracture fissures) and surficial hydrothermal eruption craters, collectively referred to in this study as hydrothermal vents. With the exception of the westernmost structure which occurs at the surface within upper bedded unit rocks, the silicified veins and breccias are hosted by the young rhyolite or within bedded rocks along or near rhyolite contacts.

The alteration in the district consists of a central silica "core" surrounded by zones of argillic and propyllitic alteration.

Vein Mineralogy

Gold mineralization at the Hart district is confined to a set of five roughly linear and parallel, northeast-trending complexes of variably banded silica veins, silicified hydrothermal vent breccias, and peripheral stockwork silica vein systems.

These irregular shaped tabular to elongate-conical bodies of silica veining form as a result of hydrothermal silicification of brecciated geothermal vents and peripheral fracture zones.

The mineralogy of the hydrothermal veins and breccias in the Hart district is relatively simple. Based on ore-petrography of silica-vein material from banded vein, vent breccia vein, and stockwork breccia vein samples the following vein paragenesis is described:

A) Early high grade banded vein filling:
- 1) quartz + adularia + pyrite
- 2) gold (up to multiple ounces/ton)
- 3) calcite + quartz (lamellar. boxwork quartz after calcite morphology) + chlorite + illite

B) Later micro- to cryptocrystalline banded vein filling:
- 1) quartz + minor scattered adularia + minor scattered pyrite
- 2) scattered, micron to sub-micron Au (approximately 1.0 ounce/ton to less than .02 ounce/ton)
- 3) calcite + chlorite + smectite + illite

Secondary vein minerals hematite (after pyrite) and alunite (± jarosite). and kaolinite wall rock alteration are the result of periodic fluid chemical fluxuations to acidic, oxidizing conditions, probably related to fluid boiling and mixing with oxygenated meteoric groundwaters.

Stockwork and vent breccia quartz veining can correlate with either A or 8. Silver content is relatively low in the Hart system. i.e. Au/Ag ≈ 3/1. Pyrite is the only sulfide mineral identified at the level of mineralization accessible during this study. This vein mineral assemblage suggest that the mineralizing hydrothermal fluid was neutral to slightly alkaline, and slightly reducing.

Alteration

Three types of alteration are defined in the Hart district:
- 1) Silicic alteration.
- 2) Argillic alteration.
- 3) Chlorite-illlte propylitic alteration.

Each of the five northeast-trending silicified fault-fracture hydrothermal vent structures define a separate silicic center with associated argillic and propylitic zones. As argillic and propylitic zones overlap to some extent, Zonation on a district scalę is poorly defined. Criteria for silicic, argillic, and propylitic alteration in the Hart district are defined below.

1) Silica Alteration: Manifested as well to poorly developed NE-striking, steeply to 55° southeast-dipping quartz + minor chalcedony veins and associated peripheral silicified vent breccias, stockwork vein systems. and sheeted zones. With one exception (the westernmost structure, Fig. 2), silicification is predominately confined to intrusive rhyolite. Bedded volcanic-sediment rocks are commonly brecciated and silicified at and near intrusive contacts. The rhyolite wallrock at the vein contacts may be strongly silicified. or "agatized," pyritization is ubiquitous with agatization.

2) Argillic Alteration: Zones of argillic alteration are those where rhyolite and(or) bedded volcanic-sediment rocks have undergone hydrothermal alteration to a variable assemblage of smectite clays (mostly montmorillonite and lesser beidellite) + moderate to abundant amounts of kaolinite + scattered illite, cristobalite. pyrite, and Fe-oxides (after pyrite). Argillically altered rocks are typically white to pink to buff to yellow with various shades of Fe-oxide staining. The key ingredients to this assemblage are co-presence of smectite and kaolinite. Kaolinite occurs up to a maximum 1/1 ratio with smectite, but is more commonly less. Localized hydrothermal alteration of rhyolite and bedded volcanic-sediment rocks produces mixtures of predominately smectite and kaolinite clays with lesser scattered illite, cristobalite, pyrite, and Fe-oxides. Argillic alteration is typically adjacent to and seldom extends far from the central silica zones. Alteration is more extensive and pervasive within bedded volcanic-sediment units than rhyolite, presumably due to their greater permeability. Argillic alteration of rhyolite is primarily confined to the wall rock immediately surrounding silicified, brecciated geothermal vents. Localized vein-wallrock alteration zonation typically consists of (from vein outwards): quartz veining - agatized and pyritized rhyolite wall rock - intense argillic altered rhyolite wallrock - less intense argillic and(or) propylitic altered rhyolite. The degree of alteration can be quite variable. Alteration can vary in the rhyolite from intense (completely clay altered) to weak argillic and(or) propylitic alteration over a few meters. Alteration of rhyolite around silicified structures is commonly in the form of fingers and pods, usually lacking continuity. In contrast, where permeable bedded volcanic-sediment rocks are in proximity to geothermal vents argillic alteration is often quite pervasive.

3) Propylitic Alteration: Propylitic alteration, as applied to this study, is a pervasive alteration assemblage affecting predominately the bedded volcanic-sediment rocks. It is generally less intense than argillic alteration and consists of various combinations of smectites, chlorite, cristobalite, illite, zeolites, pyrite. and Fe-oxides. Smectite clays (montmorillonit, and (or) beidellite, and(or) nontronite) are ubiquitous and chlorite, zeolites (heulendite, stilbite), illite, cristobalite, pyrite, and Fe-oxides (hematite, limonite-goethite) are variable. The presence of smectites in combination with chlorite and zeolites, and the absence of kaolinite are used to characterize this alteration assemblage. Propyllically altered rocks are commonly apple green when chlorite, and(or) green smectite, and (or) green zeolites are present. In the absence of these minerals, propylitic alteration can be white to buff to yellow-orange to red-brown (i.e. Fe-oxide stained).

FLUID INCLUSION STUDY

Petrographic and microthermometric analyses of quartz vein-hosted fluid inclusions produced a variety of data pertinent to the description of the chemical and physical character of the Hart district ore-forming hydrothermal fluids. This study allowed the determination of temperature of homogenization (Th) measurements of trapped two-phase (liquid-vapor) fluids within inclusions, and(or) their freezing points (Tm). These data allow direct estimates of fluid temperature at time of entrapment, and salinaty (as NaCl equivalent).

Sample selection was designed to collect data from representative hydrothermal fluid fractions across time in the Hart district geothermal system. This was accomplished by sampling sequential bands of high and low grade quartz veins in the Orobelle mine tunnel. Doubly polished plates (thick-sections) of banded quartz vein material from the Orobelle vein and doubly polished plates of vent breccia quartz vein material from outcrop above the Orobelle tunnel and peripheral to the Orobelle vein were made. In addition, chips of vent breccia vein quartz and calcite from Valley View and Chief of the Hill mines were examined. The banded vein samples represent an early to late sequence across a particular slice of time in the life of the Hart district geothermal system. They are not intended to represent the beginning to end of the system.

Petrographic observations produced: 1) inclusion morphologies; 2) Information concerning timing of formation of inclusions (i.e. primary, secondary, or pseudosecondary); 3) number and kinds of phases present within various inclusion types; and 4) relationship of various types of inclusions with respect to veining paragenesis.

Microthermometric analyses consist of various measurements taken during heating and cooling of inclusions on the heating-cooling stage. Heating measurements produce: 1) temperature estimates of hydrothermal fluids at time of trapping for various generations and types of inclusions by way of temperature of homogenization measurements (Th); and 2) negative evidence for significant presence of low density phase(s) based on lack of inclusion explosions during heating.
Cooling measurements produce: 1) freezing point depression estimates by way of final melt temperature measurements (Tm) of frozen and then heated inclusions, 2) eutectic temperature (Te) estimates based on measurement of first melt temperatures; 3) no evidence of measurable C02 based on absence of a liquid phase appearing from super cooled. frozen inclusions as temperature was raised to -56.6°C. and

lack of C02-hydrate clathrate compound formation at +7°C to +10°C; and 4) a range of metastable freezing temperatures (Tf).

Homogenization temperature data (Th) are presented in Figure 4, and freezing measurements (Tm) are presented in Figure 5.

Results of this fluid inclusion study of mineralized vein material suggest the following: (1) Mean ore stage fluid Th ≈ 170°C to 205°C. (2) Recognition of segregated and mixed zones of two-phase vapor and two-phase liquid dominant inclusions throughout ore stage quartz veins, suggesting a correlation between fluid boiling and deposition of Au; (3) Recognition of distinct populations of NaCl equivalent estimates within the range 0.18 wt% to 10.86 wt% NaCl equivalent (median ≈ 1.1 wt% NaCl equivalent); suggesting incomplete mixing of dilute and more saline fluids.

ISOTOPIC STUDIES

Strontium and oxygen-hydrogen systematics were applied in consort to the ore-petrogenesis study of the Hart gold district.

Use of 180/160 and D/H variations in this study fit the standard applications of oxygen-hydrogen isotope systematics to ore-petrogenesis studies. Specifically, this entails modeling of the origin and history of the thermal aqueous fluids involved in the formation of the Au-bearing Hart geothermal system.

Application of Sr-isotopes to this study are two-fold: (1) Use Sr as a tracer of cation solutes to model the source and history of metals in the mineralizing hydrothermal fluids throughout the life of the Hart fossil geothermal system. and (2) To provide a Rb/Sr isochron age of mineralization.

It was anticipated that correlation of the stable isotope variations with Sr isotope variations throughout a given mineralized vein forming episode during the evolution of the Hart geothermal system would allow interpretations of the origins and histories of both aqueous solution and cation solutes (metals) in solution.

Strontium Isotope Study

To determine 87Sr/86Sr systematics through time early to late bands in the quartz veins were sampled. Four samples were taken from a section of continuous, intact banded quartz vein starting with an early metal-rich. coarse to finely crystalline, high-grade layer in immediate contact with rhyolite wall rock and proceeding sequentially to the fine-grained, metal-poor layers. All samples are from the main adit of the Orobelle mine.In addition to the four quartz vein samples. whole rock samples were also analyzed. They are: (1) three rhyolite samples, at various stages of alteration; (2) three bedded volcanic/ sediment samples. at various stages of alteration; (3) two Precambrian gneissic basement samples and; (4) two NBS standards. NBS 78-A and NBS-987.

The strontium isotope study of mineralized quartz veins. country rock units. and altered host rock produced the following results: (1) Mineralized vein quartz + adularia Rb/Sr isochron age of ≈ 12.4 my; (2) Mineralized vein quartz + adularia 87Sr/86Sr calculated initial ratios that range from 8.7146 to 0.7141; (3) Altered rhyolite host rock 87Sr/86Sr calculated initial ratios ranging from 8.7133 to 8.7158. (4) Fresh rhyolite 87Sr/86Sr initial ratio estimate of 8.7110; (5) Fresh bedded sequence 87Sr/86Sr of 0.7079. (6) Fresh present day Precambrian basement 87Sr/86Sr of 0.7866.

Strontium isotope data indicate that the hydrothermal fluids contain a mixture of Tertiary magmatic. Precambrian metamorphic. and bedded sequence cation solutes (meteoric waters incorporated into the hydrothermal solution are assumed to have a 87Sr/86Sr signature similar to the average bedded sequence ratio) (Fig. 6). Mineralizing hydrothermal fluids at the Hart district apparently evolved from a magmatic fluid dominated system to a meteoric fluid dominated system. This was probably the result of flooding of the original deep source fluids with increasing amounts of meteoric waters (possibly encountering a groundwater aquifer) as the hydrothermal fluids ascended the geothermal conduits into the epithermal environment.

Oxygen and Hydrogen Isotope Study

Material used for oxygen and hydrogen isotope analyses are from the same sample set used for Sr isotope analyses. This was done to allow direct comparison of the three isotope systems against vein paragenesis and contry rock alteration. Whole vein quartz vein material was used for oxygen isotope analyses. Liberated fluid inclusion water from mineralized vein quartz material was used for hydrogen isotope analyses.

Oxygen and hydrogen isotope data, compiled on a ∂D vs ∂180 diagram (Fig. 7), suggest a mixture of magmatic + meteoric (±metamorphic) aqueous componants.

SUMMARY OF CONCLUSIONS

(1) A sequence of intermediate intercalated pyroclastlc, flow. intrusive. and associated volcanoclastic sediments were intermittently erupted and deposited on Precambrian basement over an interval irom 18.0 my to 14.0 my in the area of the Castle Mountains. This volcanic pile was subsequently intruded by a complex of rhyollte intrusives and flows at roughly 12.8 my. Eruption of the 18.0 my to 14.0 my bedded volcanics and the 12.8 my rhyolites apparently occured along northeast fissure vents. No evidence of post-eruptive magma chamber collapse (i.e. cratering) is indicated.

(2) Field relations show gold mineralization at the Hart district to be spatially and temporally related to Castle Mountain rhyolite intrusions.

(3) Gold mineralization at Hart is confined to banded silica veins and peripheral siliciiied hydrothermal breccias hosted primarily by 12.8 my rhyolite flow-dome complex rocks.

(4) Mineralized silicified structures are commonly separated by Interspersed masses of strong argillic alteration. This relationship exists at a wide range of scales (from inches to hundreds of feet).

(5) Gold mineralization is structurally controlled. Mineralized silica veins and silicified hydrothermal breccias are confined to NE striking, steeply SE dipping to vertical fault-fracture structures.

(6) Intersection of subordinate WNW structures with the locally dominant NE structures apparently created zones of high fracture density and localized ascending hydrothermal fluids as conduit-vent systems. Three of these structural intersections - paleovents correspond with the locations of the largest zones of gold mineralization in the Hart district.

(7) Argillic alteration grades rapidly into chlorite propylitic alteration away from mineralized zones of silicification.

(8) The Ag content is relatively low in the Hart system (Au/Ag ≈ 3/1), and pyrite is the only sulfide identified at the level of mineralization observed during this study.

(9) Mean ore stage fluid temperatures are estimated from fluid inclusion Th data to have been in the 170°C to 205°C range.

(10) Fluid inclusion data indicate that the mineralizing fluid was a poorly mixed mixture of dilute and more saline aqueous fluids.

(11) The recognition of both segregated and mixed groups of two-phase vapor dominant and two-phase liquid dominant inclusions throughout ore stage quartz bands suggests a correlation between fluid boiling and Au deposition.

(12) The ore stage silica vein mineral assemblage indicates that the mineralizing hydrothermal fluids were neutral to slightly alkaline and slightly reducing.

(13) A Rb/Sr isochron age date of mineralized silica vein material suggests the age of mineralization at Hart to be approximately 12.4 my.

(14) Strontium and oxygen-hydrogen isotope data.suggest that the mineralizing fluid at Hart was a mixture of magmatic + metamorphic + meteoric cation solute and aqueous solution components. The fluid apparently became more meteroric dominated as it ascended into the epithermal environment, possibly mixing with and eventually becoming flooded by meteoric groundwater.

(15) Based on the Hart district vein mineral assemblage and type of alteration the assumed chemistry of the ore forming fluids is consistent with an "adularia-sericite," low sulfur type epithermal precious metal deposit. However' the association of mineralization with intrusive rhyolites and the apparent magmatic

contribution to the fluid and solute componants is more consistent with an"acid-sulfate," high sulfur type epithermal precious metal deposit.

(16) Gold mineralization at Hart formed in a structurally controlled. Tertiary volcanic hosted epithermal geothermal system characterized by high energy, high flow rate episodes of hydrothermal flow accompanied by periodic hydrothermal eruption events.

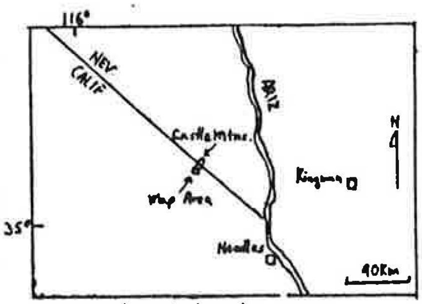
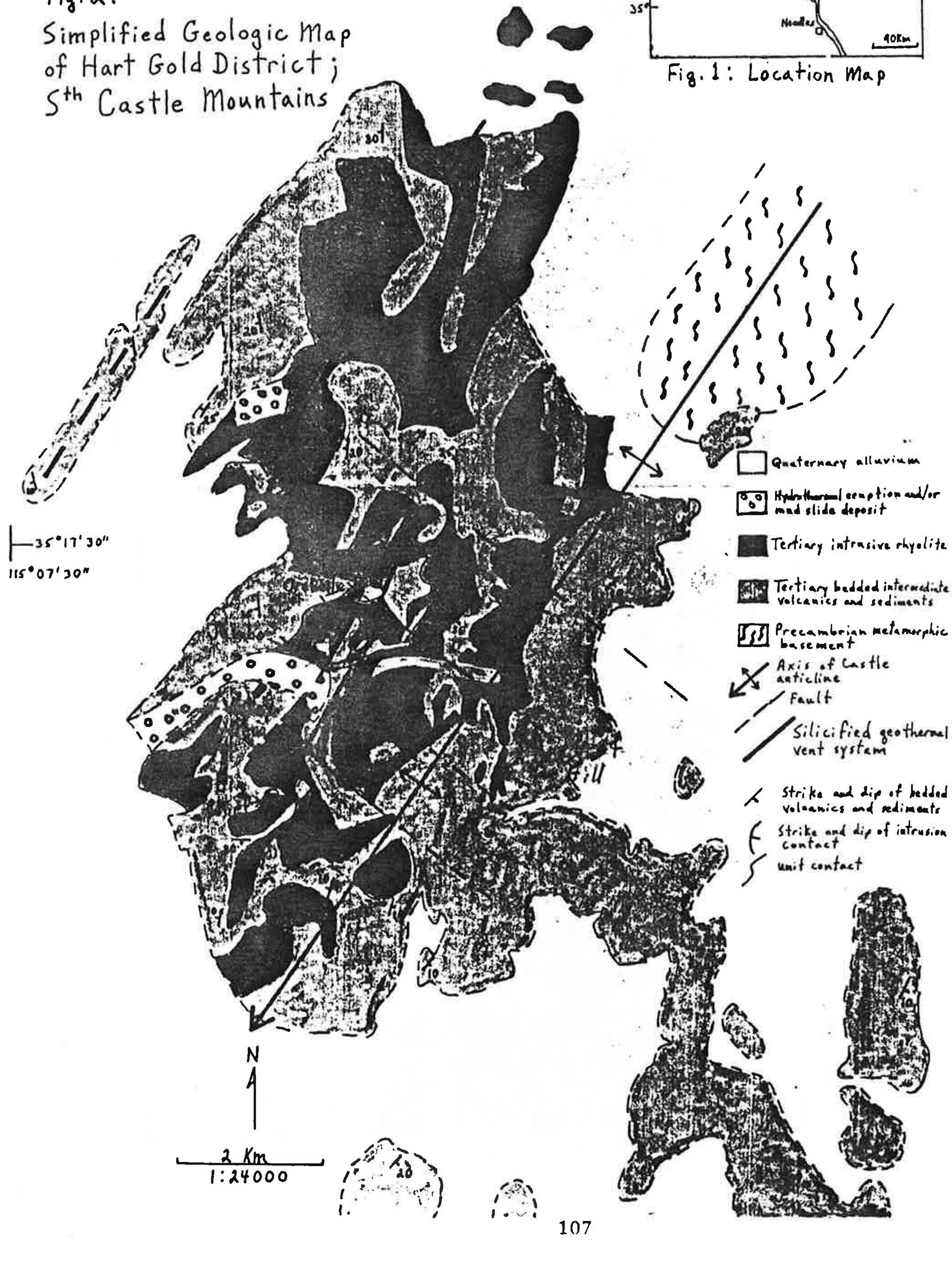


Fig. 1: Location Map

Fig. 2:
Simplified Geologic Map of Hart Gold District; S^th Castle Mountains



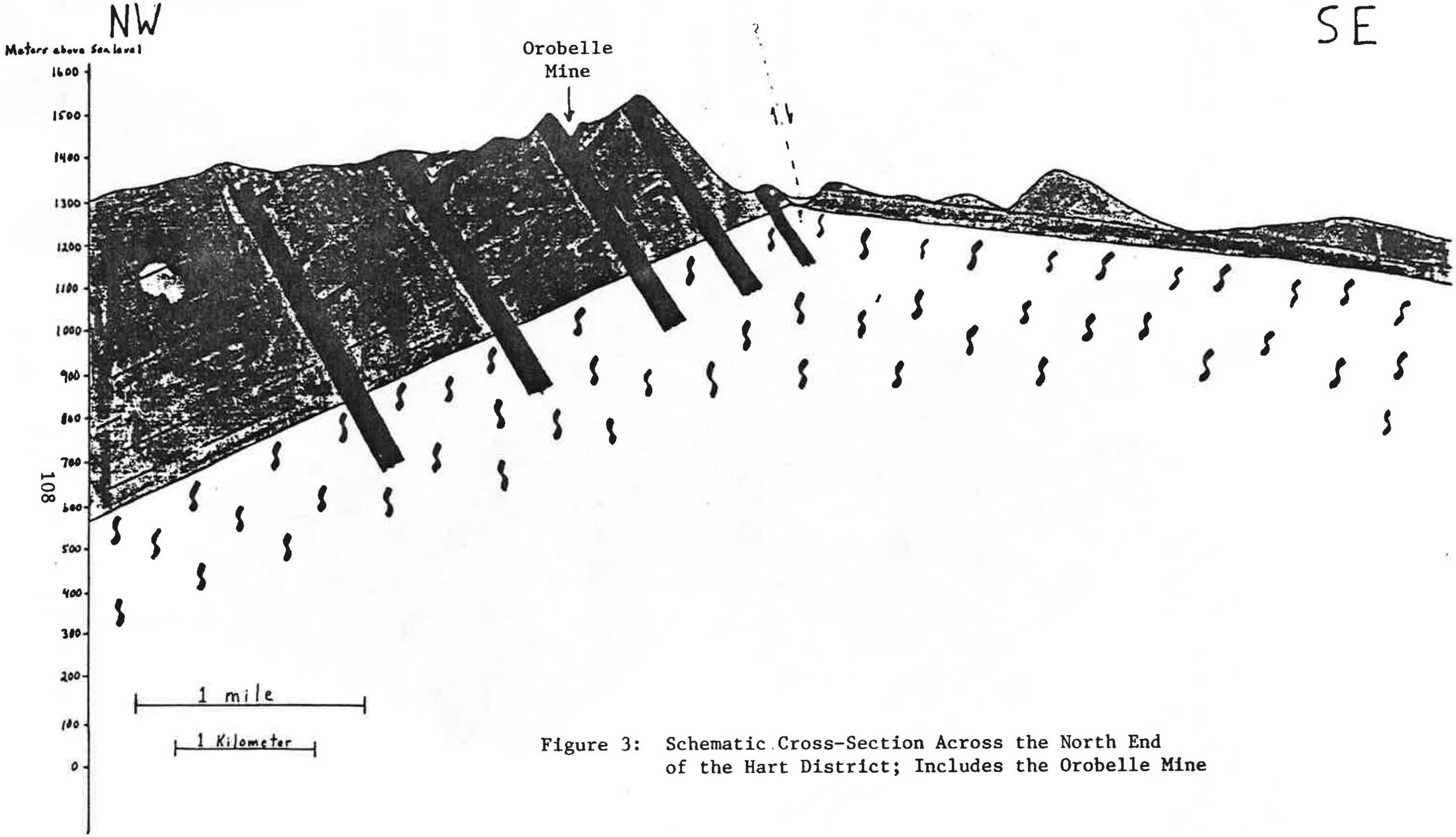


Figure 3: Schematic Cross-Section Across the North End of the Hart District; Includes the Orobelle Mine

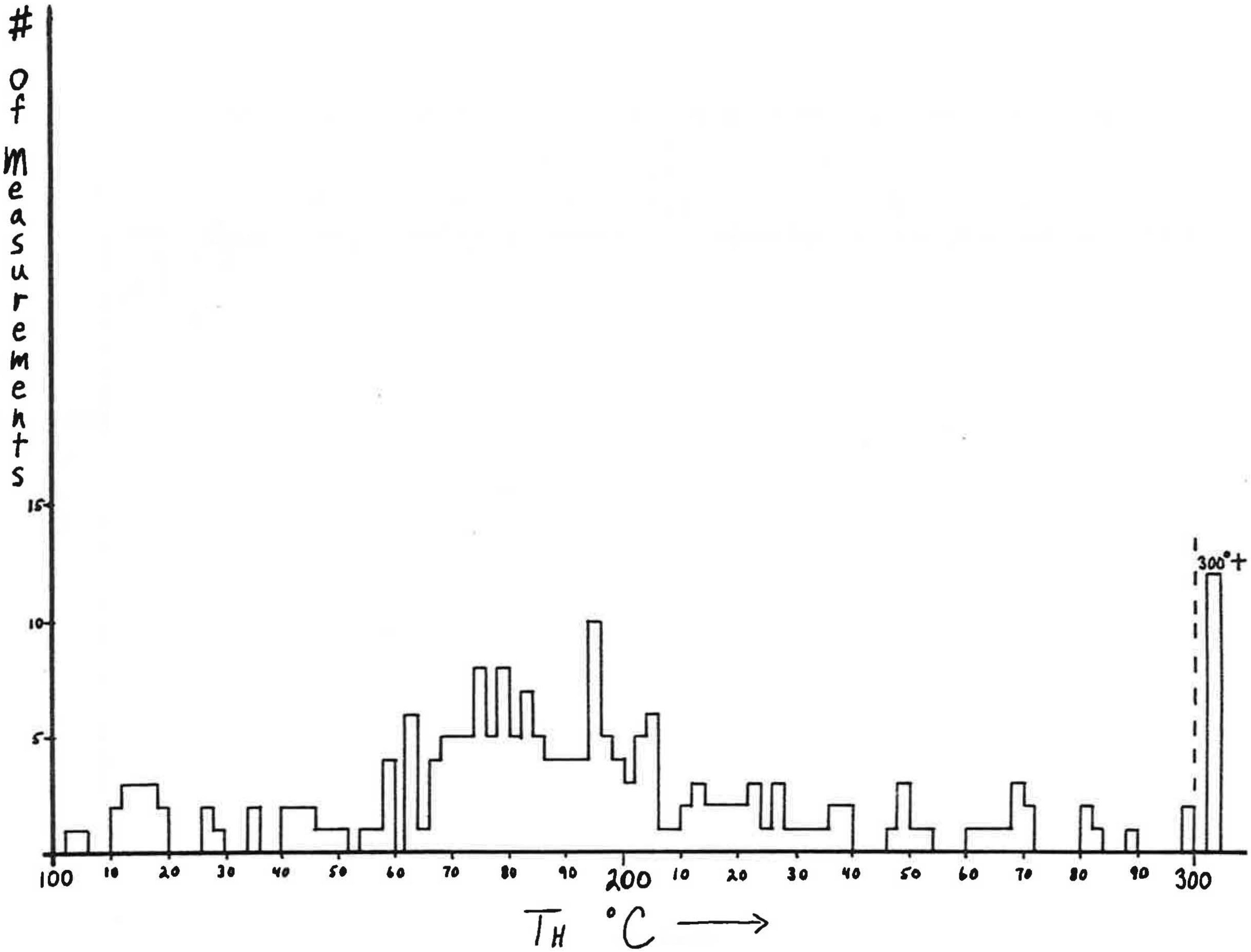


Figure 4: Frequency Diagram of Fluid Inclusion Homogenation Temperature Measurements

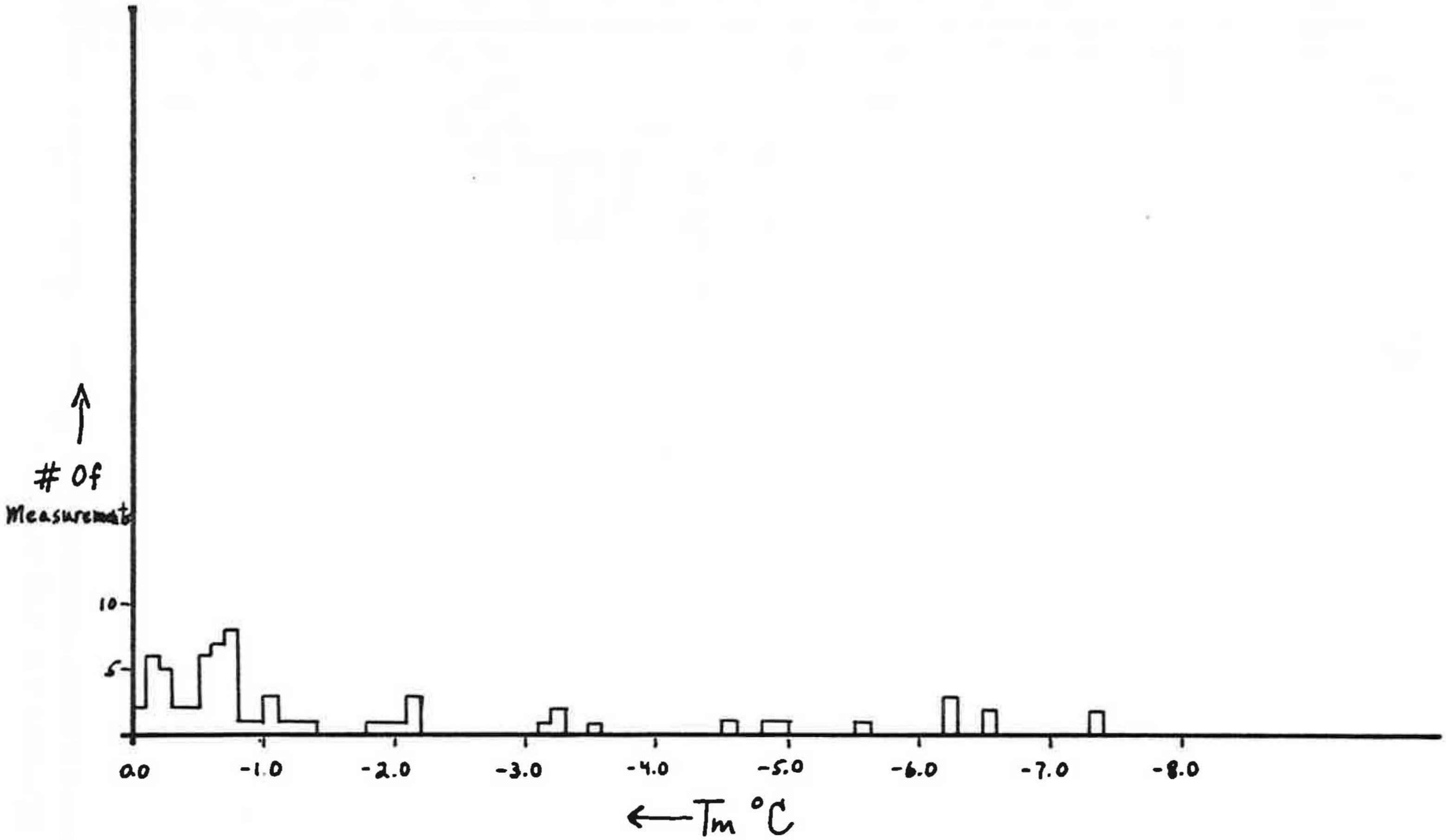


Figure 5: Frequency Diagram of Fluid Inclusion Melting Point Measurements

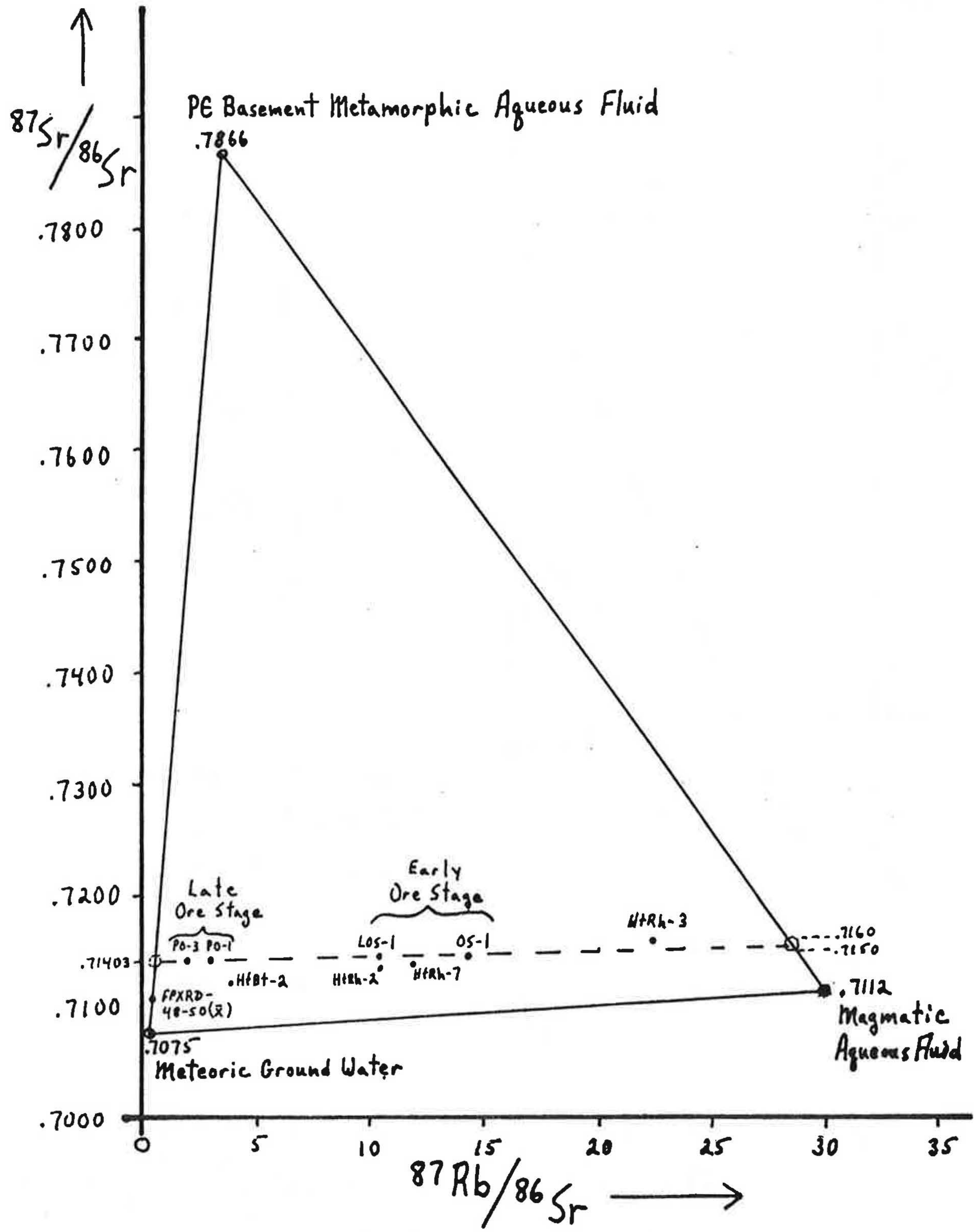


Figure 6: $^{87}Sr/^{86}Sr$ vs. $^{87}Rb/^{86}Sr$ Ternary Diagram Showing Proposed Sr Mixing Line for Hart District Ore Forming Hydrothermal Fluid

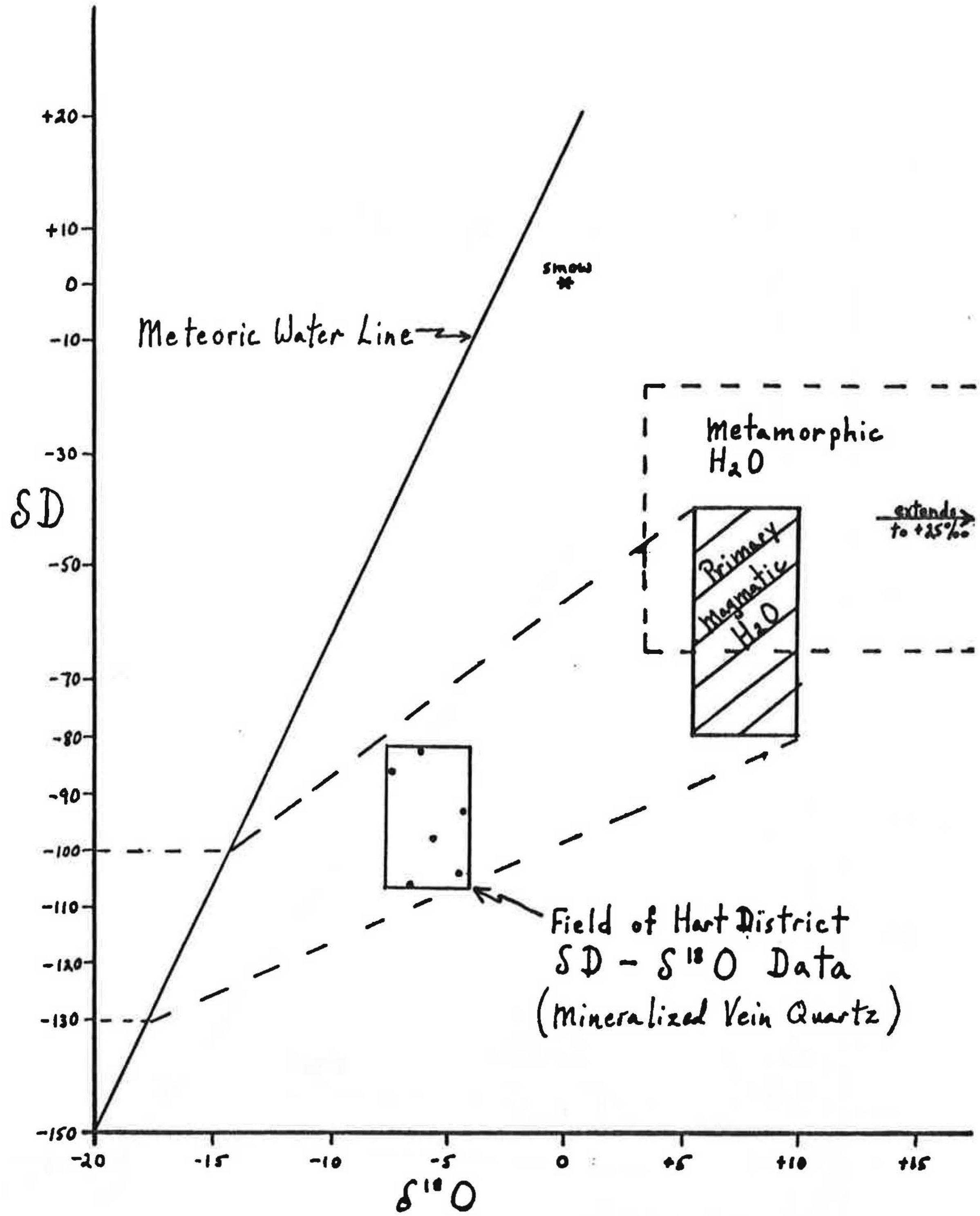


Fig. 7: Standard δD vs $\delta^{18}O$ Diagram Illustrating The Oxygen-Hydrogen Isotopic Signature of Hart District Ore Forming Hydrothermal Fluid. Note The Location With Respect To The Magmatic H_2O Meteoric H_2O Field of Mixing

The Ivanpah Project of the Mojave Gold Province -- A Structural Approach

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Abstract

Homestake Mining Company's Ivanpah project is located on the southeast flank of the Ivanpah Mountains approximately 70 road miles southwest of Las Vegas, Nevada. Current exploration has focused on an area one-half mile south of Vanderbilt Gold Corporation's Morning Star mine.

The project area lies within the late Jurassic Ivanpah granite which is an early phase of the larger Teutonia batholith. The area occurs at the southern end of the Sevier orogeny thrust belt.

Gold mineralization occurs predominantly as 1-65 micron prills of electrum along limonite, quartz, and calcite filled fractures.

Stress field orientations and movement directions on major faults were determined using structural data collected from the Morning Star mine. Both open pit and underground observations indicate at least three and possibly four fault sets. Beginning with the earliest set, the Morning Star fault, movement was determined to be oblique right-lateral slip with a weak normal component. No evidence was found to support the current thrust fault classification. The second fault set developed as a NNW oriented right-lateral, reverse, oblique-slip fault. The third set developed as a NNE-striking normal faults.

The final set occurs as an ENE-oriented, right-lateral, normal, oblique-slip fault. Field observations indicate this set developed penecontemporaneously with an early barren hydrothermal phase producing abundant white clay minerals within and adjacent to the fault plane. All previous fault sets were altered similarly but to a significantly lesser extent. Later, ore-mineralizing fluids entered each of the fault sets, but were greatly inhibited in the ENE set due to a damming effect from the white clay alteration in minerals therein.

Areas of increased fracture density contain more ounces of gold. Therefore, at zones of intersecting fractures better mineralization occurs particularly where fluids were confined by a nearby aquatard.

Application of knowledge gained from the structural analysis including structural geometries, fault movement directions, ore trends, alteration controls and the characteristics of the plumbing system responsible for ore mineralization, has produced very favorable results. Accurate drill targeting in areas with considerable colluvial cover has become increasingly possible.

Accuracy and confidence of geologic interpretations made from reverse circulation drill chips have significantly improved. Alteration patterns, gangue mineralization and mylonite fabrics noted in drill cuttings are now more significant and meaningful.

Recognition of ore trends and fracture orientations has prompted optimization of drill hole orientations. This has improved representativeness and locally tenor of drill results.

Introduction

Homestake Mining Company's Ivanpah project is located on the southeastern flank of the Ivanpah Mountains approximately 70 road miles southwest of Las Vegas, Nevada (fig. 1). Current exploration work has focused on an area one-half mile southeast of Vanderbilt Gold's Morning Star open-pit gold mine. The Morning Star mining operation and the Ivanpah exploration project are both situated in northeastern San Bernardino County, California in the East Mojave National Scenic Area which was created in 1981 and encompasses approximately 1.5 million acres of land within the California Desert District.

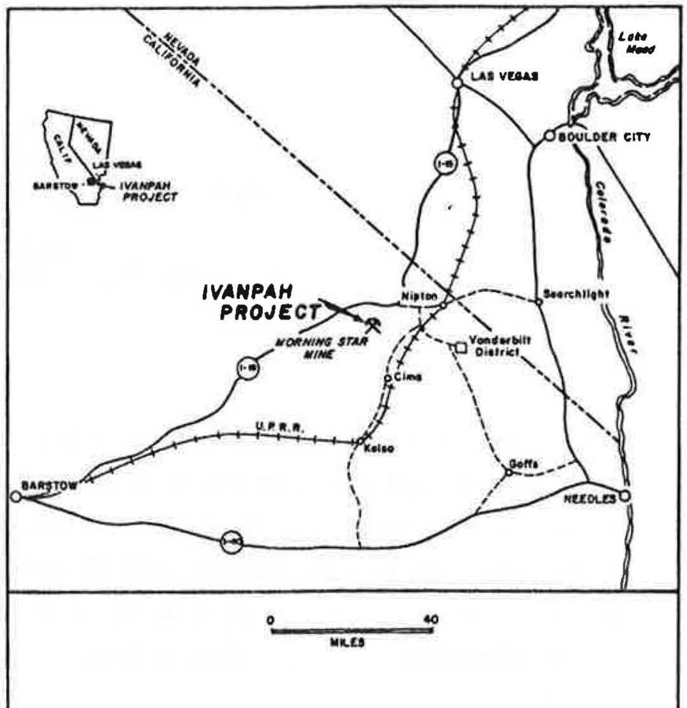


FIG. 1

INDEX MAP
IVANPAH PROJECT
SAN BERNARDINO COUNTY, CALIFORNIA
C. Byington, January, 1988

History

The earliest recorded mining activity in the area occurred after the first wagon road was constructed across the region in 1861. By the late 1860's several Ag-Cu-Au mines had been discovered in what are now the Clark Mountain, Standard and Ivanpah mining districts. Production peaked in the 1880's and ceased after the Silver Panic of 1893.

Discovery of the Morning Star deposit occurred in 1907 with sporadic exploration and production following until in 1930 the property was acquired by Haliburton Oil Company. Haliburton completed extensive underground exploration and development defining nearly 2,000,000 tons of reserves, but the mine was closed by War Production Order L208 prior to production (Wrede and Jordan, 1987).

Vanderbilt Gold Corporation acquired the property in 1964 and began development utilizing trackless underground mining methods in 1974 with the first ores milled in 1983. In late 1985 the mine was converted to an open pit operation and a cyanide heap leach system was developed with production scale leaching beginning in late 1985 (Wrede and Jordan, 1987).

Homestake Mining Company acquired an adjacent property position in early 1986 and has been exploring the Morning Star and Sunnyside fault systems since that time. Exploration methods utilized include surface mapping, rock chip and soil geochemical sampling, geophysics, and, most recently, drilling and structural analysis.

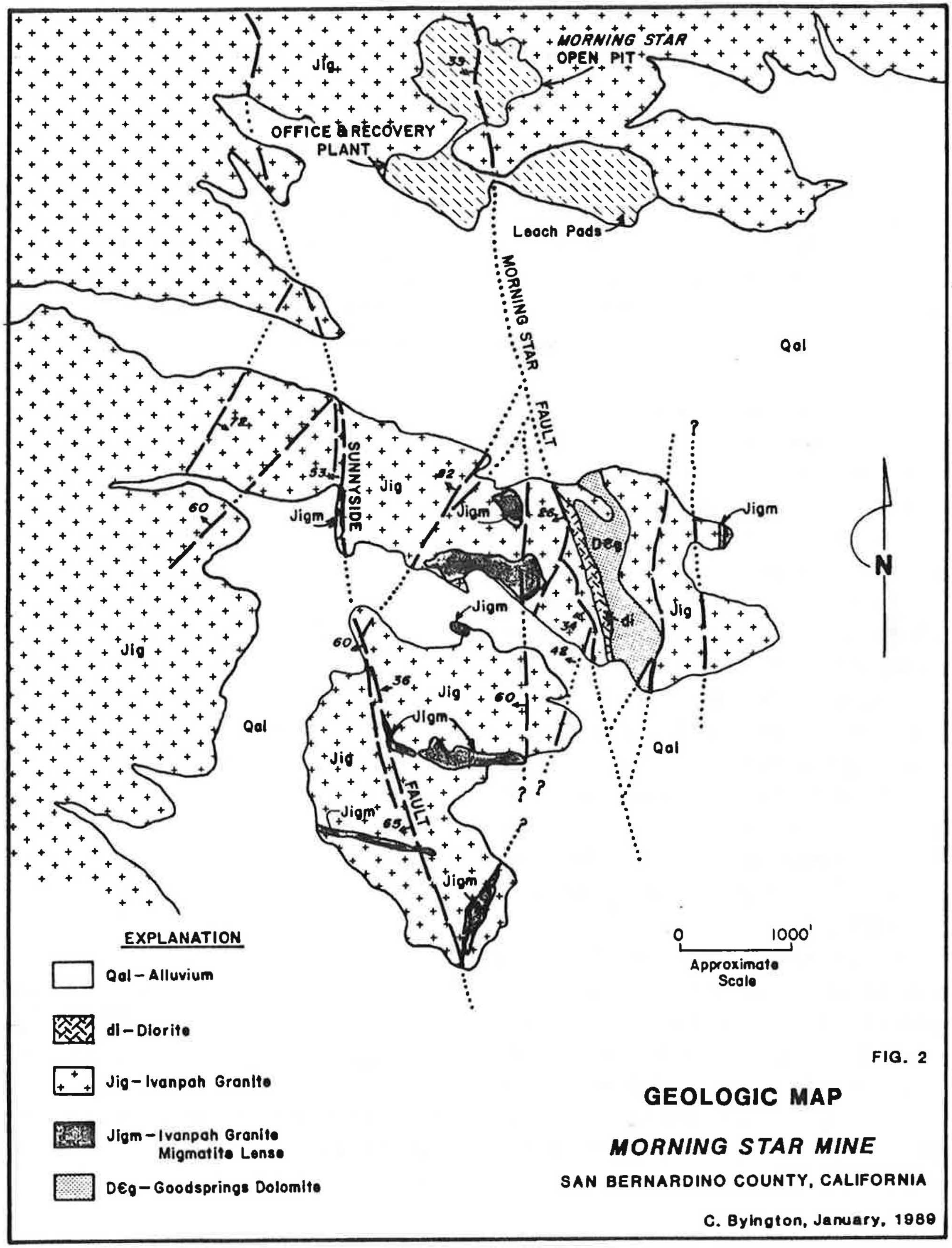


FIG. 2

GEOLOGIC MAP

MORNING STAR MINE

SAN BERNARDINO COUNTY, CALIFORNIA

C. Byington, January, 1989

Geologic Setting

The Ivanpah project lies within the late Jurassic Ivanpah granite of the Teutonia batholith. The 137 m.y. (Sutter, 1968), coarse grained granite appears to have concordantly intruded, dilated, and locally assimilated the Paleozoic sedimentary host in the area. Local rafted blocks and pendants of sedimentary rocks remain (fig. 2).

The area lies near the southern end of the Sevier orogeny thrust belt. Thrusting apparently pre-dates intrusions associated with the Teutonia batholith. Although thrusting may have occurred in the Paleozoic rocks prior to intrusion, no evidence supporting thrusting in the Ivanpah granite could be found.

Gold mineralization is localized most abundantly in the hanging walls of both the Morning Star and Sunnyside faults as 1-65 micron inclusions in quartz, calcite, sulfides and exsulfides. Veining varies from 1-30 millimeters in width and is predominantly composed of quartz. Rarely preserved sulfides include cubic pyrite, chalcopyrite, galena, sphalerite and covellite. Gold most commonly occurs as electrum along limonite-encrusted fractures.

Structural Analysis

Over 150 select fracture orientations were measured from the pit walls of the Morning Star mine. Crosscutting relationships along with primary and secondary alteration features were noted as compared to each other and mineralization.

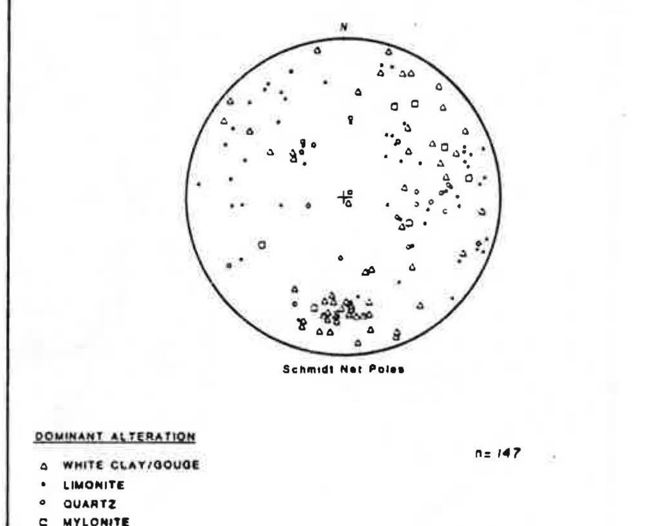


FIG. 3

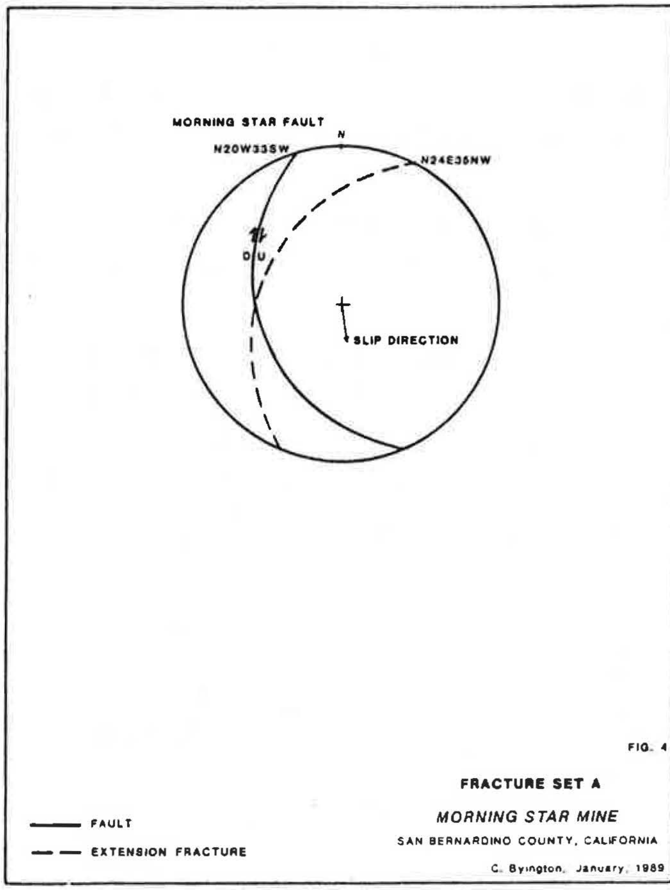
OPEN PIT
FRACTURE RELATED ALTERATION
AND MINERALIZATION
MORNING STAR MINE
SAN BERNARDINO COUNTY, CALIFORNIA
C. Byington, January 1989

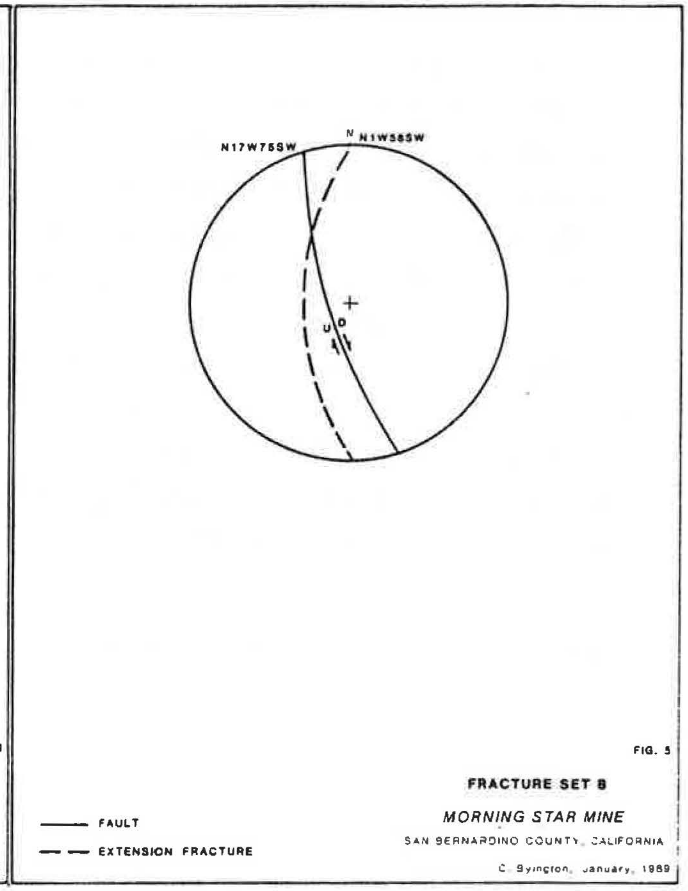
Four general distinctions were readily apparent with respect to alteration and mineralization of the fractures (fig. 3). The first of these includes fractures containing gouge, white clays and sericite. Locally limonite or rarely pyrite could be found bordering or crosscutting these fractures.

The second and by far the most abundant mineralization feature includes limonite coated fractures. Local compositional variations were noted although the limonite content averages about 60-70% goethite.

Locally quartz filled fractures were also noted. These veinlets most frequently are 2-5 millimeters in width and several meters in length and often contain microscopic, disseminated pyrite ± other sulfides.

Finally mylonite/sericite zones occur along select faults such as the Morning Star fault and associated fractures. The mylonite fabric is typified by elongated quartz and orthoclase phenocrysts surrounded by very narrow foliated bands of sericite, rock flour, and locally chlorite. Frequent undulatory extinction and Böhm lamellae in quartz phenocrysts are additional microscopic features indicating strain.





Results from the various categories defined by the above stated relationships were plotted as poles on the stereonet and statistically averaged for each group. The representative orientations for each group were then plotted as indicated by the field relationships to define the movement directions and stress field orientations (figs. 4-8).

The above analysis indicates three distinct fault sets with a fourth set possible. The Morning Star fault set appears to have developed first as indicated by crosscutting relationships and alteration features. This set appears to have uniquely formed in a brittle/ductile transitional environment whereas subsequent faulting occurred as brittle deformation only.

The main shear of the Morning Star fault is oriented N20°W33°SW with a N24°E35°NW extension fracture set. Given that relationship, the structural geometry indicates a low-angle right lateral strike slip fault with a weak normal component. No evidence was found to support the current thrust classification of this fault (Burchfiel and Davis). Field evidence including fracture relationships, slickensides, and alteration phenomena collected in the open pit and throughout the project area by the authors as well as underground data collected by Vanderbilt Gold's geologists confirms the above interpretation (Wrede, unpublished).

The second fault set consists of a N17°W75°SW trending main shear and N1°W58°SW extension fractures (fig. 5) indicating right lateral reverse movement on this steeply dipping set. The principal stress direction at this point had migrated to the southwest (fig. 8) from that creating the Morning Star faulting.

Normal movement dominated a weakly-documented, possible third set (fig. 6). The main shear is oriented N23°E69°SE with extension fractures developing at N23°E80°NW. Because field evidence for this set is weak its position in the fault sequence is uncertain. The principal stress direction migrated back to the northeast at this time about midway between the two previous sets (fig. 8).

The final recognized fault set (fig. 7) required an eastward migration of the principal stress direction. The main shear occurs at N89°E65°NW and the extension fractures developed at N70°W76°NE. Right lateral, normal, oblique-slip movement is indicated for this set (fig. 8).

Hydrothermal alteration began penecontemporaneously with development of the final east-west fault set. A "white clay" mineral suite possibly composed of sericite and montmorillonite clays developed particularly well in the finely comminuted gouge. All of the other fault sets experienced the "white clay" alteration but not to the extent of the east-west set. This is due to an apparent open(ing) position of these fault conduits resulting from recent movement, and in part to the increased reactivity to hydrothermal alteration of the fine gouge particles.

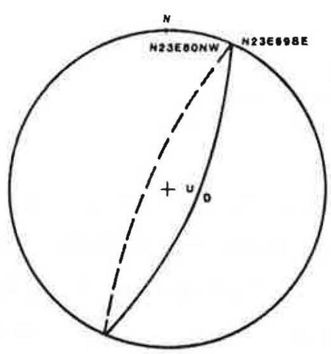


FIG. 6

FRACTURE SET C

MORNING STAR MINE

SAN BERNARDINO COUNTY, CALIFORNIA

C. Byington, January, 1989

——— FAULT

— — EXTENSION SET

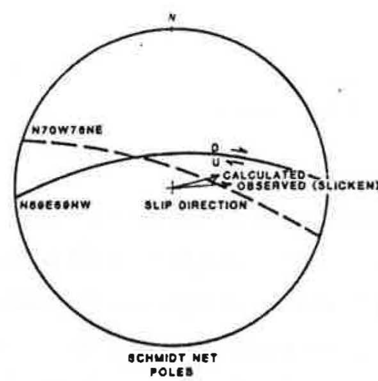


FIG. 7

FRACTURE SET D

MORNING STAR MINE

SAN BERNARDINO COUNTY, CALIFORNIA

C. Byington, January, 1989

——— FAULT

— — EXTENSION FRACTURE

As is typical particularly with normal faulting, fracture densities are considerably greater in the hanging wall than the footwall. The "white clay" alteration is confined predominantly to the hanging wall in the general mine area due to the increased fracture density, and most importantly, to a thick, altered-fault gouge/clay aquatard developed locally along the Morning Star fault plane.

Lateral and vertical fluid flow of subsequent mineralizing fluids was largely controlled by the existing plumbing system. Fluid migration and mineral precipitation were enhanced in areas of higher fracture density and permeability. However, downward migration of fluids as shown by Larson and McCormick (1985) was prevented below the Morning Star fault by the above mentioned aquatard. Lateral flow also was strongly inhibited by the damming effect of a handful of through-going, east-west, "white clay" fractures as revealed in the pit walls by current mining at the Morning Star.

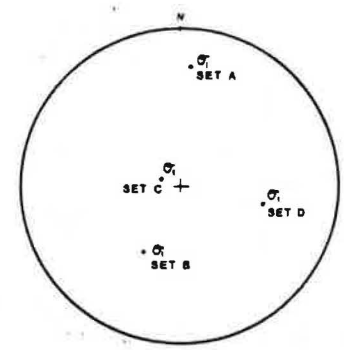


FIG. 8

MIGRATION OF PRINCIPLE STRESS DIRECTION
MORNING STAR MINE
SAN BERNARDINO COUNTY, CALIFORNIA
C. Byington, January, 1989

Limonite and quartz mineralization occurs in all of the fault sets to varying degrees. Steeply dipping fractures oriented more northerly acted as the best conduits for mineralizing fluids.

Fracture patterns developed as a consequence of repeated faulting created zones of increased permeability, particularly along lines of intersection. These zones of increased fracture density then might be expected to host more gold per unit volume of rock. Such was found to be the case (fig. 9).

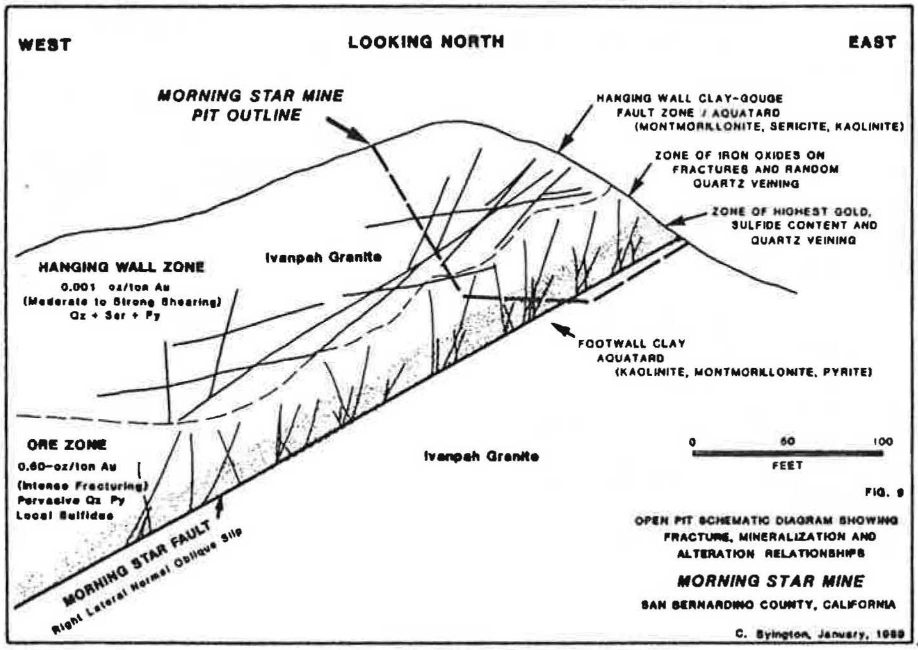


FIG. 9

OPEN PIT SCHEMATIC DIAGRAM SHOWING FRACTURE, MINERALIZATION AND ALTERATION RELATIONSHIPS
MORNING STAR MINE
SAN BERNARDINO COUNTY, CALIFORNIA
C. Byington, January, 1989

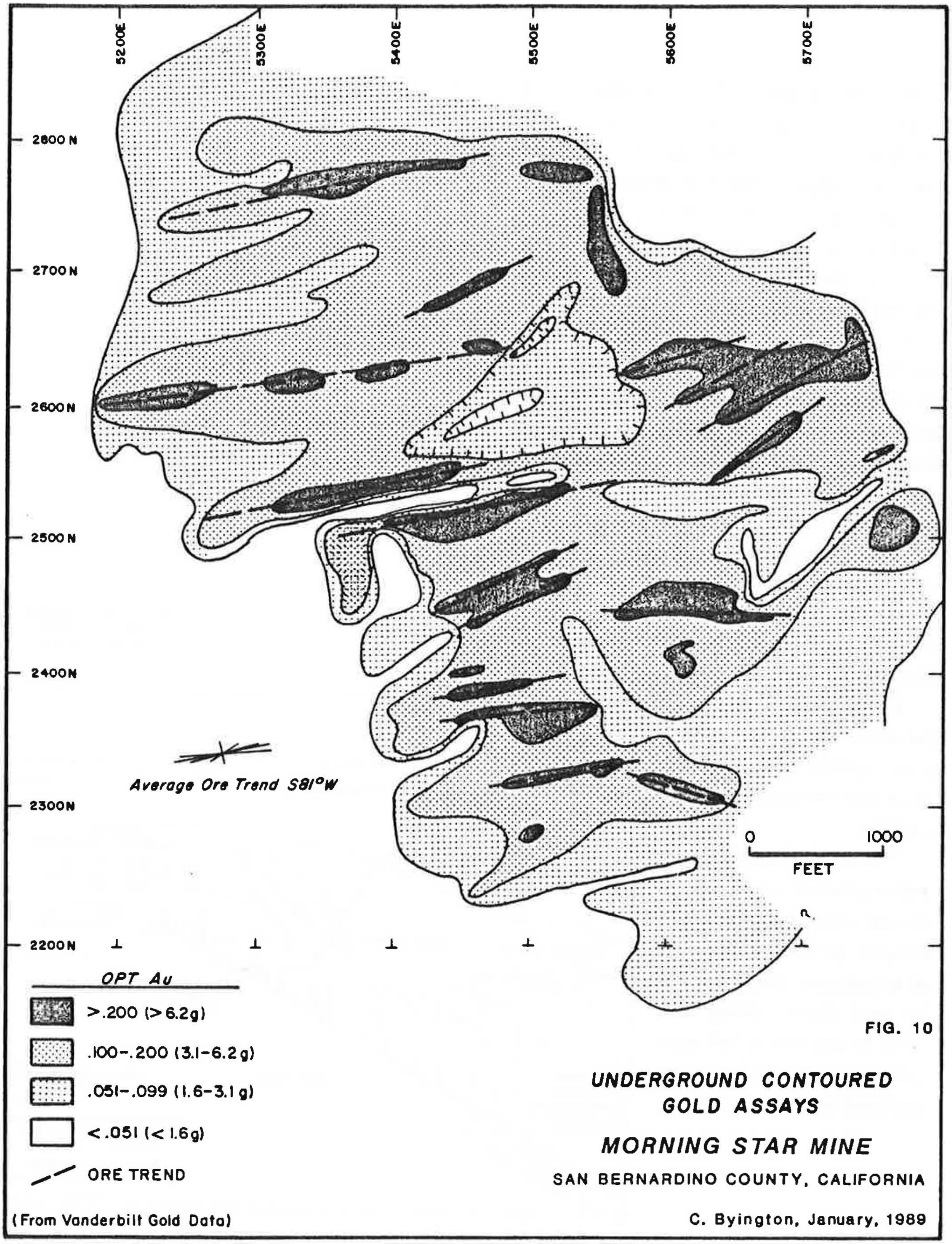


FIG. 10

UNDERGROUND CONTOURED GOLD ASSAYS

MORNING STAR MINE

SAN BERNARDINO COUNTY, CALIFORNIA

Underground gold assay results from Vanderbilt's early mining were contoured as projected to plan view (fig. 10). A very dominant S81°W trend evident from this map suggests a systematic control on mineralization. The high gold grades occur as discontinuous, east-west elongated pods, a phenomena recognized in early underground mining (J. Jordan, personal communication).

Fracture orientations measured from currently non-existent underground workings were obtained by Larson and McCormick (1985) as part of an in situ leach study. The composite of fractures from all levels within the mine (fig. 11) indicates three dominant fracture sets. The intersection of the N68°W76°SW and N22°E65°NW fractures rakes subparallel to the dip of the Morning Star fault. The two other fracture intersections rake obliquely up-dip into the fault plane.

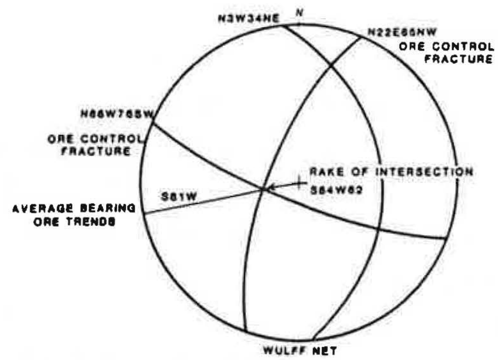


FIG. 11

COMPOSITE-ALL LEVELS

(MODIFIED FROM LARSON, W.C., & McCORMICK, T.H., 1985)

MORNING STAR MINE

SAN BERNARDINO COUNTY, CALIFORNIA

C. Byington, January, 1989

The rake of the down-dip fracture intersection (S84°W62°) and the average ore trend bearing (S81°W) correlate very well, strongly suggesting these fracture orientations are controlling the higher grade mineralized zones. In addition the inclination of the rake of the intersection explains the discontinuity of high grade pods. The intersection zones rake into the Morning Star fault at an inclination of 62° whereas the fault dips at 33°. These zones of fracture intersection therefore pass into, but not through the fault for reasons explained previously. Plan views of these zones would be expected to show high grade pods elongated along the rake bearing (S84° ± W), and which would die out in a short horizontal distance.

Drill-Hole Follow Up

Understanding the structural geometries, movement directions, ore trends, alteration controls, and the generalities of the plumbing system were instrumental in determining subsequent drill hole placement.

Recognition of ore trends and ore-hosting fracture orientations are currently being used to optimize drill hole orientations. Results from this optimization have consistently improved the representativeness of drill results. Areas showing poor Au mineralization in previous drilling have shown very significant increases with optimized drill orientations.

The area targeted with the majority of drilling activity to date is covered with a thick colluvial blanket; there is no surface expression of mineralization where drilling has defined better gold grades. More conventional methods of detection such as geochemical sampling and geophysical testing have not been productive in identifying mineralization. Such is very often the case throughout this desert region.

Projection of "hard data" considerable distances under the colluvial cover has been requisite in identifying this mineral resource. Results from drill cuttings are now more confidently and accurately interpreted, and features such as clay, limonite and quartz have become more meaningful.

To date, 87 drill holes have been completed in the project area. Due to the area being located within the East Mojave National Scenic Area, protection of natural, scenic, and cultural resources of the region is of special concern as it pertains to mineral exploration and mining activities in this part of the California Desert Conservation Area. The project site is located along the margin of recognized crucial desert tortoise habitat in the Ivanpah Valley and several locations within the exploration area contain potential for identification of historic resources associated with past mining.

Drilling activities have been planned so as to avoid disruption of tortoise populations in the general area and associated burrow sites. Additionally, identified areas of potential historic resources have been avoided until proper inventory of potentially significant sites can be documented and, as necessary, mitigated prior to disturbance. Drill sites and associated access roads required to support drilling activities have been concurrently reclaimed with drilling operations so as to minimize environmental impacts.

Acknowledgments

We express our gratitude to Messrs. John (Jack) Jordan and Kent Ausburn of Vanderbilt Gold Corporation for many insightful discussions and for allowing access into the Morning Star open pit.

We also wish to thank Homestake Mining Company for allowing this publication and Toni Hutcherson for patiently compiling it into its present form.

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GEOLOGY AND GOLD MINERALIZATION AT BLACKHAWK MOUNTAIN, SAN BERNARDINO COUNTY

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ABSTRACT

The Blackhawk (Santa Fe) mines, credited with an historic gold production of over 10,000 ounces since their discovery in 1887, have been the site of intense exploration sampling and drilling in recent years. Most of these activities, including a 1988 bulk testing program, were aimed at establishing bulk mineable reserves in an extensive zone of Fe-alteration around the old workings. The results have indicated significant mineralization in localized areas along more than 2000 ft of exposed section. However, the mineralization is very erratic and major parts of the alteration zone are unmineralized. The property is controlled by Amerigold Inc., who are currently constructing a small pilot production plant.

The mineralization and alteration are contained in the hanging wall of a major regional thrust zone in brecciated marbles of the Carboniferous Furnace Formation. The immediate footwall consists of argillized Precambrian gneiss. Mineralogical, geochemical, and fluid inclusion studies point to a multi-stage Process of gold mineralization. The primary gold mineralization occurs in narrow base metal-rich quartz-sulfide veins and replacement bodies, and also in quartz-sericite altered igneous dikes. A late stage oxidizing event, probably coincident with regional thrusting and argillite alteration caused nearly complete sulfide destruction and widespread mobility of Fe-oxides along with partial mobilization of precious metals. The remobilized gold coprecipitated with Fe-oxides in the matrix of the marble breccia. The primary phase of mineralization is related to CO2-bearing saline aqueous fluids with temperatures around 800 degrees C. This reflects a skarn-type mineralization in response to the emplacement of porphyritic dikes related to a Mesozoic age quartz monzonite intrusive. The proposed model may have implications for precious metal exploration along the northern range front of the San Bernardino Mountains.

INTRODUCTION

The Blackhawk/Santa Fe mines are located along the north slope of the San Bernardino Mountains, 15 miles Southeast of Lucerne Valley (Fig. 1). The first gold prospects in this area were discovery between 1870 and 1890, and several of the mines were intermittently active on a small scale until 1941. Total historic production is estimated at 10,000 ounces of gold, most of it produced in the 1920's. A detailed account of the colorful history of gold mining in the Blackhawk district is given by Ely (1982).

The mine adits are situated at the head of Blackhawk Canyon in the source region of the well-known Blackhawk/Silver Reef landslide. Some of the adits are within large bodies of the landslide that rest on the north facing mountain slope. The main part of the landslide forms a six-mile long lobe at the base of the canyon. Detailed descriptions of this impressive Quaternary landslide and of the general geology in Blackhawk Canyon are given by, among others, Woodford and Harris (1928), Shreve (1988), Stout and Wattenbarger (1989).

Three well defined groups of prospects and mines can be distinguished in the Blackhawk Canyon area; these are known as the Cliff, Lookout, and Santa Fe areas (Fig. 2). Gold mineralization in these three areas occurs in intensely brecciated marbles in the lowermost portion of the Carboniferous Furnace Formation. The marbles are separated by a thrust fault from the underlying Precambrian Baldwin gneiss. The package that contains the gold mineralization shows extensive red coloration due to a hematite/Fe-oxide induration of the breccia matrix. Zones of carbonaceous marble breccia, and of intensely bleached breccia are also present.

The lodes that supported most of the old producers were associated with zones of intense to nearly massive hematite/Fe-oxide alteration. Underground prospecting and mining along these zones proceeded to a depth of over 300 feet.

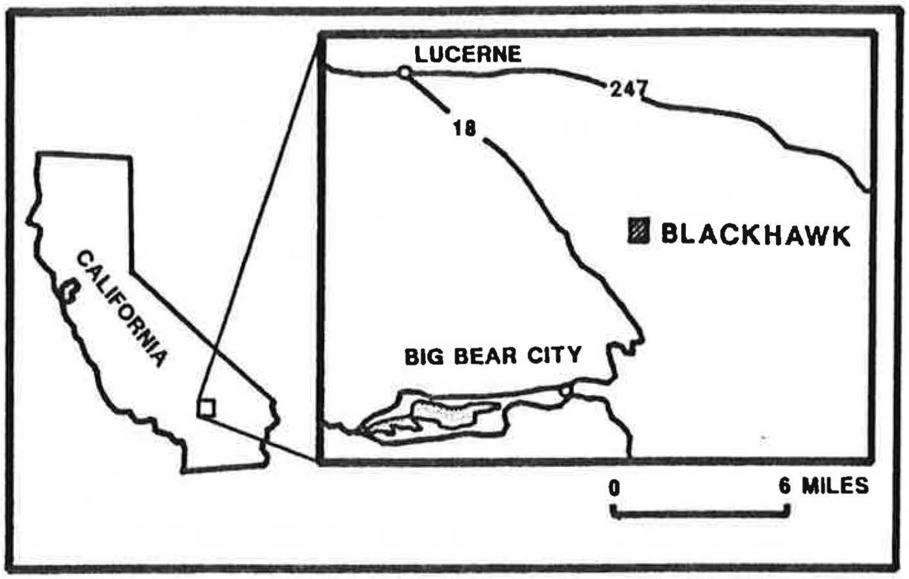

Figure 1. Location of the Blackhawk area

Since the late 1970's the Blackhawk area has been the site of several new exploration campaigns. These recent activities were geared towards establishing low-grade bulk-mineable targets in the laterally extensive Fe-oxide altered areas around the old workings.

The property is currently controlled by Amerigold Inc., who are in the process of setting up a small-scale pilot production plant processing ore from the Cliff area.

The present contribution summarizes the results of some of the exploration and research activities carried out in 1988. The program consisted of bulk sampling and drilling supported by detailed geological mapping of target areas, geochemical sampling, and microscopic studies. Fluid inclusion studies were conducted to provide more quantitative data on the nature and the temperature of the mineralizing fluids.

GEOLOGY

Lithology

A geologic map of the Blackhawk Canyon area is presented in Fig. 2. The Precambrian Baldwin Gneiss is the oldest formation present and it forms the dominant rock type in the southern part of the canyon. The gneiss is medium-grained, well foliated and contains abundant amphibole and biotite. A well-developed zone of argillized gneiss is exposed in the immediate footwall of the Santa Fe thrust in the Cliff, Lookout and Santa Fe mine areas (Fig. 2). This zone has been affected by intense tectonic fracturing and hydrothermal bleaching, which has imparted a light green color to the rock.

The Carboniferous Furnace Formation occurs as a tectonically shattered block of medium- to coarse-grained, poorly bedded dolomitic marbles resting on top of the basement gneiss and mantling Blackhawk Mountain. Brecciation is locally very intense, especially in the Cliff and Lookout area. The Furnace Formation is the primary source material for the numerous slide breccias which have been deposited along the western wall of Blackhawk Canyon.

Hornblende-hornfels contact metamorphism in response to the regional intrusion of plutonic rooks in Mesozoic times (Richmond, 1960) is responsible for the recrystallization of the limestones and the formation of a metamorphic assemblage which consists primarily of calcite, dolomite, tremolite, muscovite, epidote, and locally diopside and garnet. Extensive alteration zones of bleached and Fe-oxide stained marble are developed in the lower portion of the Furnace Formation. Although these zone appear to follow the Santa Fe thrust, detailed mapping by Wattenbarger (1989) in the Blackhawk district has demonstrated their presence in many other locations, unrelated to thrusts and other faults; he correlates their development with the intrusive/metamorphic event. This is supported by Dibblee (1982), who reports a frequent occurrence of these zones in marble near intrusive contacts throughout the San Bernardino range.

A quartz monzonite of Mesozoic age is the dominant lithology in the northernmost portion of Blackhawk Canyon. The quartz monzonite intrudes the Baldwin gneiss and hosts a series of pervasively shattered porphyritic and aplitic dikes and sills. Sulfide-bearing and altered porphyritic dikes intrude the Furnace Formation at the Cliff and Santa Fe areas. The dikes are cut off by the Santa Fe thrust system and they predate the tectonic shattering of the marbles. Porphyritic dikes similar to the ones described above are rather common in this part of the range. Compositional similarities between porphyries and quartz monzonite suggest that they had a common magmatic parentage, and may be nearly the same age (Miller, 1987; Dibblee, 1982). Throughout the range, the dikes are frequently associated with carbonate-hosted base and precious metal deposits (Richmond, 1980).

The unmineralized Tertiary Old Woman sandstone forms low, rounded buff-colored hills. The sandstone contains numerous gravel horizons and weathers rapidly to arkosic sediments. In the Lookout and Cliff mine area the sandstone is overlain by a series of Quaternary slide breccias (Shreve, 1968). These breccias consist of chaotic marble rubble zones, but also comprise large semi-coherent transported segments of the Santa Fe thrust zone.

Structure

The most prominent structural feature in the Blackhawk area consists of a series of E to ESE-trending low-angle thrust faults. These are part of a major regional low-angle fault system along the northern range front of the San Bernardino Mountains. The Voorhies thrust separates the Tertiary Old Woman sandstone from the overlying Precambrian gneiss. The gneiss, in turn, is overthrusted by Furnace Formation marbles along the Santa Fe thrust. The Santa Fe fault contact is characterized by intense brecciation, numerous shear planes, and a clayey gouge up to 40 feet thick. The thrustzone dips south and the dip increases with depth from 10 to over 30 degrees as indicated by drillholes and underground workings. The thrust system has been offset by several high angle normal faults which are part of a regional NW-trending system.

The youngest structural event involved the slide breccias along the western wall of the canyon in the Lookout and Cliff area. The breccias are related to the large Blackhawk landslide at the foot of the mountain. Most of the west side of Blackhawk Canyon is affected by the slides. The presence of marble rubble breccia underneath altered basement gneiss suggests that the Cliff and Lookout zones are large, essentially intact units that were transported northward during large-scale Quaternary landslide events. These units include segments of the Santa Fe thrust and underlying basement.

MINERALIZATION AND ALTERATION

Gold mineralization occurs within the lower portion of the intensely brecciated marble package. The auriferous zones are located immediately above the main thrust, but they are also found higher up in the sequence. At first sight, the distribution of the old prospects and mines suggests an overall correlation between gold mineralization and hematite/Fe-oxide and clay alteration in the lowermost 100 feet of the marble breccia (Fig.2). These alteration zones are near horizontal and their exposed strike length in the canyon exceeds 2000 ft. This gives the impression of a large disseminated gold system along the hanging wall of the thrust zone.

However, the results of rock chip sampling, drilling, and detailed geochemical and mineralogical studies clearly indicate that the association between gold and Fe-oxide alteration is not necessarily valid. The gold distribution is much more restricted than the Fe-oxide alteration, and gold occasionally occurs outside the alteration zones. Our study concludes that the primary distribution of gold is controlled by two types of relatively small-scale features: sulfidic quartz veins and replacement bodies (type 1), and altered igneous dikes (type 2). These two types of primary mineralization have been overprinted by a late stage, very intense oxidation event that caused complete in-situ destruction of the sulfides resulting in pockets, lenses and veins of fine-grained siliceous hematite/goethite aggregates. This was accompanied by widespread mobilization of Fe-oxides, and only limited mobility of gold. The Fe-oxides precipitated in veinlets, fractures, voids, and irregular trails in the marble breccia, and created an extensive zone of Fe-oxide alteration in the lower portion of the Furnace Formation. Gold reprecipitated on original type 1 gold grains, and some was transported for an unknown distance (possibly several feet) and coprecipitated as fine inclusions in the secondary Fe-oxides.

Type 1 gold mineralization is associated with base metal sulfides (Cu, Pb, Zn) in discontinuous quartz veins and narrow siliceous replacement lenses (mantos) in the marble. They have been observed in underground workings at the Santa Fe and also in drill intercepts at the Cliff and Lookout areas. The mineralized zones are discontinuous, and generally less than one foot wide. The attitude of the veins

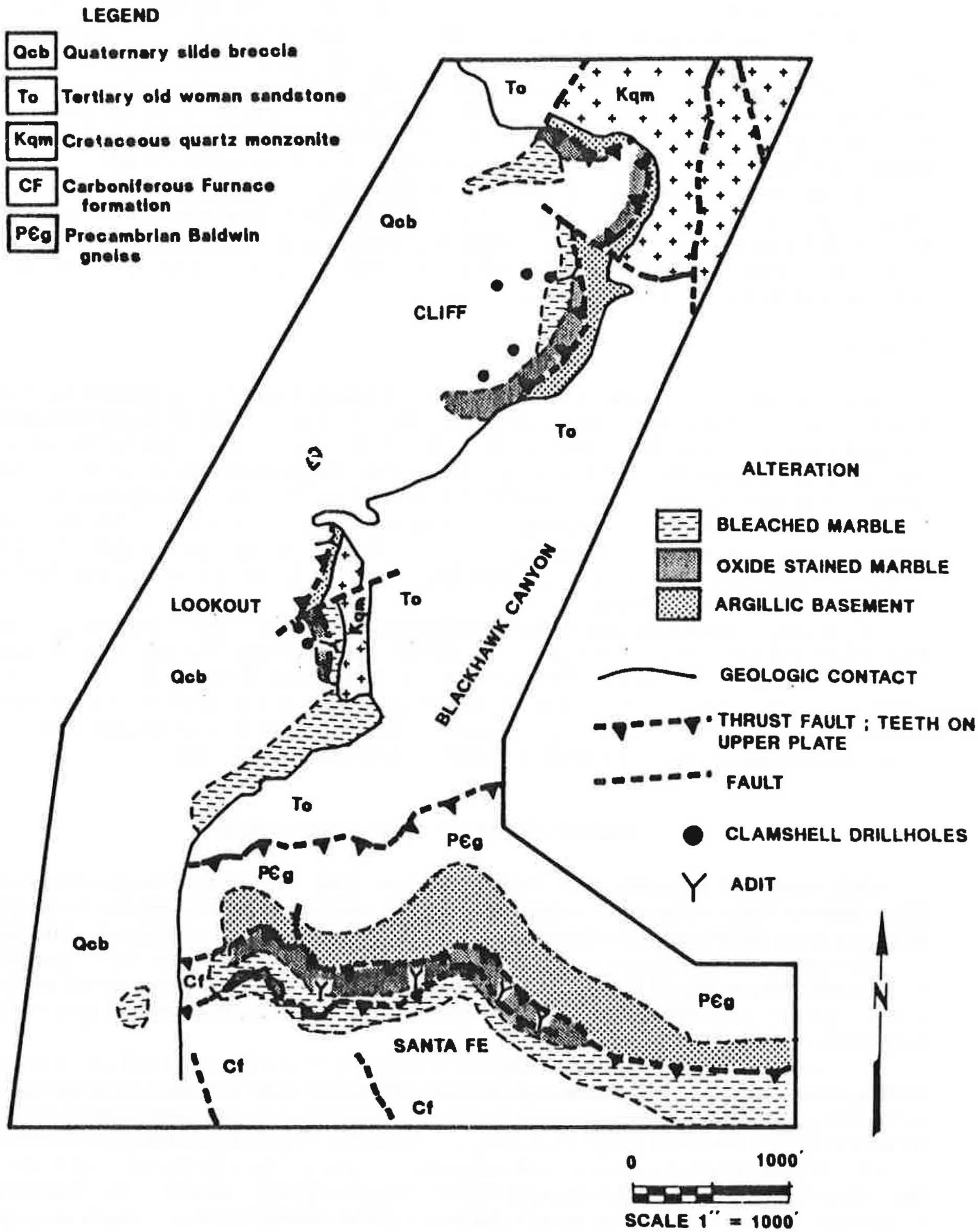

Figure 2. Generalized geologic map of the Blackhawk Canyon area. After Wattenbarger (1989).

and lenses varies wisely from near horizontal, conformable to the Santa Fe thrust system, to steeply inclined. The observed mineralogical association consists of quartz, pyrite, galena, sfalerite, chalcopyrite, and gold. Comparable precious metal occurrences have been described elsewhere in the district at the Lester, Rose, and Baldwin Lake mines (Richmond 1960).

Type 2 gold mineralization is associated with dike- and sill-like bodies consisting of fine-grained quartz-muscovite aggregates. These dikes/sills occur adjacent to the shearzones in the Santa Fe hematite altered marbles, but they have also been observed higher up in the sequence (Cliff area). They are up to 6 feet wide and they can be traced for several hundred feet along strike, semi-concordant to the overall gently S-dipping structure. They contain discontinuous quartz veins, some with aggregates of oxidized Pyrite. The dikes and included quartz veins are often boudinaged and the quartz is intensely fractured. These bodies are interpreted to represent porphyritic dikes, similar to igneous dikes found elsewhere in the area, that were pervasively altered to a muscovite-quartz +/- pyrite assemblage.

The pockets and lenses that were formed by complete in-situ oxidation of the type 1 auriferous sulfide-quartz mineralization display powdery deep purple red, honey brown, and occasionally black colors. The mineral assemblage is composed of a wide variety of secondary minerals including Fe-oxides, Cu-oxides, Pb-sulfates and carbonates, and wulfenite. Calcite occurs in crosscutting veinlets. Visible gold is easily detected upon panning of crushed material.

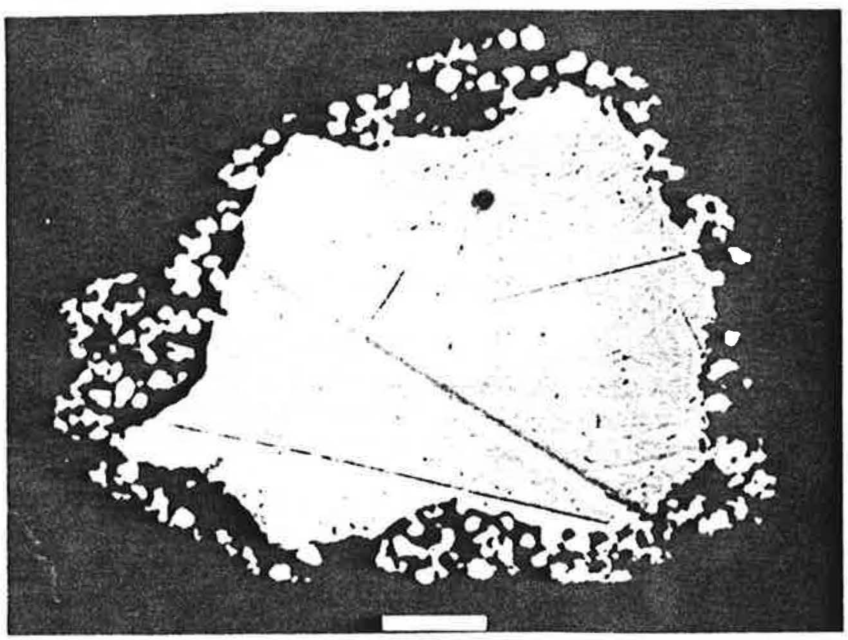

Figure 3. SEM backscatter electron image of a silver-rich gold particle showing overgrowth of ultrapure native gold (white rim and white inclusions) intergrown with hydrous iron oxides (black). Scale bar is 10 microns (Baum, 1989).

The altered marble breccia package displays a distinct vertical color zonation. The red hematitic/ Fe-oxide zone is overlain by a dark grey carbonaceous zone, which is up to several tens of feet thick. This, in turn, is overlain by a White bleached limestone breccia. contacts are sharp, but irregularly waving, and reminiscent of leaching/precipitation fronts. The alteration zones appear semi-conformable to the gently dipping bedding. Drilling has demonstrated that these zones continue for an appreciable distance along dip. Argillic alteration is confined to gneisses in the footwall of the Santa Fe thrust and to green, white, and red colored clay zones, several feet thick, in the brecciated marbles higher up in the sequence. The alteration assemblage consists of montmorillonite, kaolinite, calcite, chlorite, and jarosite. These argillic zones typically do not carry anomalous gold values.

Gold Mineralogy

As shown by mineralogical test studies (Baum, 1988) gold occurs as free particles, often associated with quartz, and as inclusions in Fe-oxides. Grain size varies widely, but most particles are in the 20 to 40 micron range. Larger grains up to 200 microns are not uncommon and some inclusions in Fe-oxide are submicron size. The free gold particles are rich in silver (30-50%) but the inclusions in Fe-oxides are virtually pure gold. Occasionally the electrum grains are rimmed by a zone of pure gold and/or by a Fe-oxide zone with pure gold inclusions (Fig.3).

The goethite/Fe-oxide contains anomalous levels of Cu, Zn and Pb, and is associated with malachite, plumbojarosite, and wulfenite. Textural evidence shows that some of the Fe-oxides formed by in situ oxidation of pyrite. Most of the Fe-oxides, however, display low temperature precipitation/gel textures.

GEOCHEMISTRY

The gold contents of the oxidized siliceous pockets and veins (type 1) is generally over 1 oz/ton, up to a maximum of 7.5 oz/ton. Silver values range up to 15 oz/ton. The precious metal grades drop sharply outside the boundaries of these pockets. The quartz-sericite altered igneous dikes (type 2) show erratic gold grades, with values between 0.01 and 0.1 oz/ton and low silver contents.

Detailed surface and drill sampling shows a strong positive correlation between gold and base metals. Values up to 10 wt% combined Cu, Pb, Zn are not uncommon for some samples that contain in excess of 1 oz/ton gold. Systematic analysis for As, Sb, Hg, and Mo did not reveal significant anomalies except for some of of the highly sulfidic samples. This may indicate the presence of primary sulfosalts. Spectrographic scans indicate the local presence of anomalous levels of cadmium and tungsten.

Gold and base metal anomalies are only found in the marbles in the hanging wall of the Santa Fe thrust. They are not restricted to particular alteration zone. No anomalies were found in the argillized footwall, nor in the thrust gouge.

The silver:gold ratios of the samples show a distinct bimodal distribution. Most values fall in a range from 0.2:1 to 2:1 but values around 4:1 are common for some of the very sulfidic (galena-rich) samples and samples with extremely low gold values.

FLUID INCLUSIONS

A detailed study on fluid inclusions from the Blackhawk Canyon area was presented by Wattenbarger (1989). Samples were studied from several auriferous Fe-oxide rich siliceous pods in brecciated marble in the hanging wall of the Santa Fe thrust and late-stage calcite veins in argillized gneiss from the footwall. Also included was a pegmatitic dike in quartz monzonite located in the footwall, at a considerable distance from the thrust plane.

This study revealed the presence of two populations of fluid inclusions: 1) CO2-rich inclusions homogenizing at moderate temperatures, and 2) inclusions lacking CO2 and homogenizing at lower temperatures. Each population is related to a different phase of hydrothermal activity in the Blackhawk area.

Both types of inclusions contain a moderately saline aqueous fluid. CO2 is present in quartz in the siliceous pockets and in the pegmatite dike. The CO2 occurs in three-phase inclusions that homogenize in the liquid phase around 800 degrees C (Fig. 4). Salinities range from 0 to 9 wt.% NaCl equivalent, and CO2 contents vary between 0.17 and 0.23 mol.% CO2. No evidence was found for boiling. Some inclusions in the siliceous pods show characteristics of primary origin. Two-phase aqueous inclusions occur as secondary inclusions in all samples studied. Those in the siliceous pods homogenize in the liquid phase around 200 degrees (Fig. 4), and those in the late stage calcite veinlets in the argillic alteration zone show homogenization temperatures ranging from 100 to 180 degrees C. Salinities in both types range between 0 and 4 wt.% NaCl equivalent. They do not show evidence of boiling.

The CO2-bearing inclusions in the siliceous pods are interpreted to be related to the primary phase of mineralization in the area. The presence of CO2, and the moderately high homogenization temperatures and salinities are characteristic of inclusions formed during late-stage skarn development related to the emplacement of epizonal silicic plutons (Bodnar, 1986). The presence of similar inclusions in the

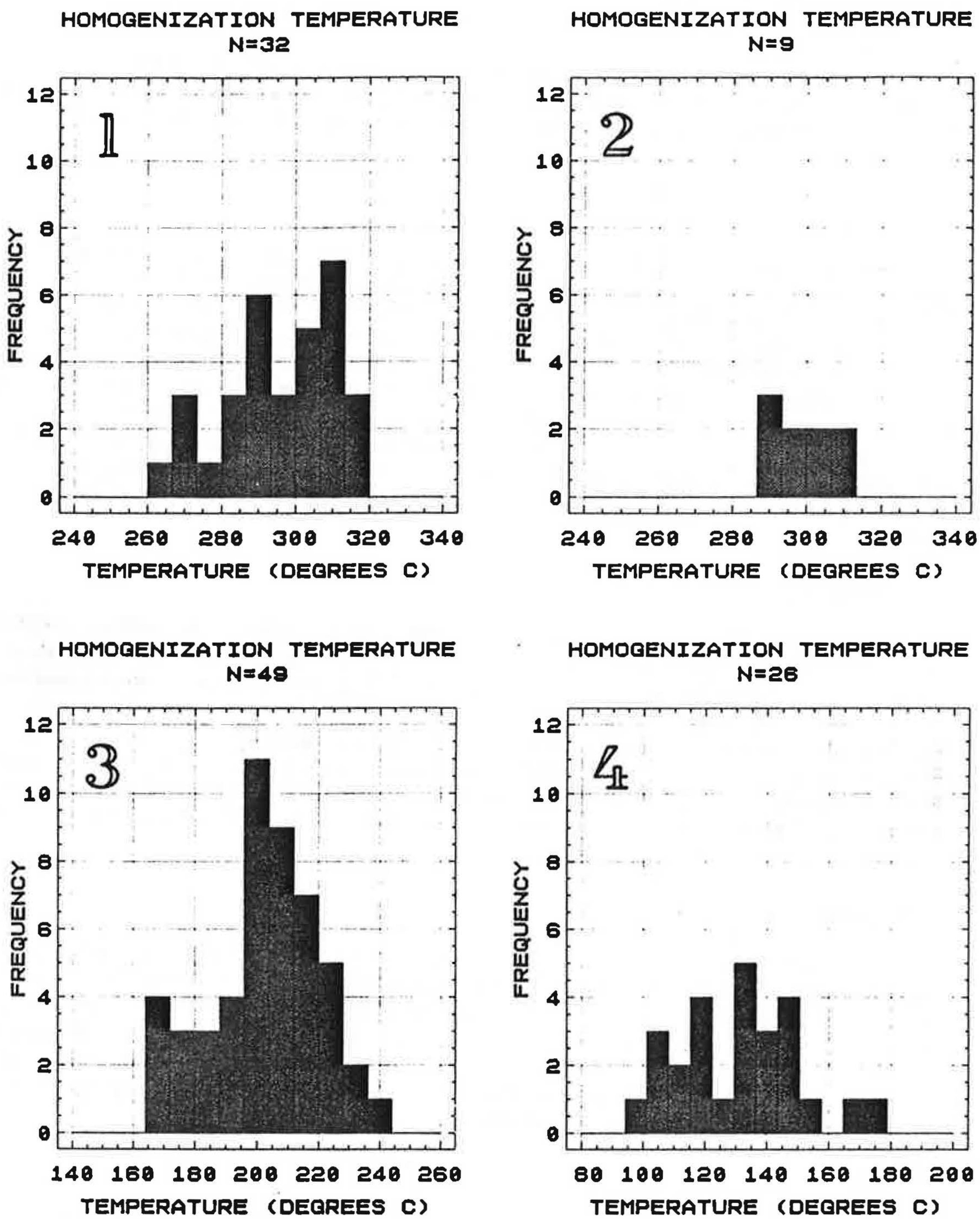

Figure 4. Homogenization temperatures of fluid inclusions from the Blackhawk area (after Wattenbarger, 1989).
1: CO_2-bearing inclusions in siliceous marble-hosted lenses.
2: CO_2-bearing inclusions in pegmatite dike cutting quartz monzonite, east side Blackhawk Canyon.
3: Aqueous inclusions in siliceous marble-hosted lenses, adjacent to Santa Fe thrust.
4: Aqueous inclusions in calcite veins hosted by argillic gneiss, adjacent to Santa Fe thrust.

pegmatitic dike in the quartz monzonite suggests a close relationship between the skarn-type hydrothermal episode responsible for the siliceous sulfidic bodies and a late stage magmatic emplacement of porphyritic dikes.

The CO2-free aqeous inclusions are related to a later phase of argillic alteration associated with epithermal fluids in the 100 to 200 degree C range. This phase was structurally controlled by the Santa Fe thrust system and was associated with the Quaternary uplift of the San Bernardino Mountains.

EXPLORATION

Most recent exploration efforts at Blackhawk were aimed at establishing bulk-mineable low-grade reserves in the laterally extensive zones of Fe-oxide altered marble breccia. These zones are locally up to 100 ft thick. Pre-1988 drilling and surface sampling campaigns indicated a highly irregular gold distribution in this target zone. Some of this was attributed to serious sampling problems caused by the irregular grain size distribution of the gold (nugget effects) and the brecciated nature of the host.

The 1988 program initiated by Billiton was designed to overcome sampling problems by taking bulk surface and drill samples in addition to the standard surface sampling and mapping procedures. Bulk sampling also provided sufficient material to test a wet screening procedure to upgrade the ore. Since gold was thought to reside mainly in the finer-grained breccia matrix, it was generally believed that the material could effectively be upgraded by discarding, after washing, the marble breccia fragments.

Bulk Sampling

The central Santa Fe area was tested by 12 bulk surface samples collected by backhoe at different elevations in the target zone over a strike length of 800 ft. Each sample represented a vertical section of approximately 10 ft and weighed about 5000 lbs. The Cliff and Lookout zones were tested by 7 shallow large diameter drillholes completed by a Yost clamshell excavator. The clamshell is a compressed air type excavator, Widely used in placer evaluations. Digging is performed by a 3 ton tool lowered and raised by a steel cable. The Yost clamshell excavates a 3 ft diameter hole and produces a sample of about 5000 lbs for each 5 foot interval. Excavating the rather loosely cemented limestone breccia down to 125 ft posed no major problems, although progress (up to 35 ft/day) was somewhat less than in a routine placer evaluation.

Processing

The backhoe samples and each 5 ft drill sample were transported to a wet screening facility at the mouth of the canyon. This processing facility consisted of an hydraulic powered triple deck vibratory screen (1/2", 1/4", and 1/8" screens) with three rows of spray bars on top of the upper screen. Throughput capacity was about 3 tons/hr. The underflow slurry was directed through an automatic sampler device to a series of settling ponds. The sampler collected about 10 to 20% of the total minus 1/8" undersize and this sample (100 to 800 lbs) was sent to thelab for drying and assaying. Head samples were collected systematically before the screening process.

Results

At the Cliff and Lookout zones, significant gold mineralization was only encountered when oxidized quartz-sulfide veins and massive siliceous Fe-oxide/goethite pockets were intercepted by the clamshell. The best results include a section of 20 ft averaging 0.51 oz/ton (for minus 1/8" screened material) at the Cliff zone and a 30 ft section averaging 0.079 oz/ton (minus 1/8" material) at the Lookout. These mineralized zones are not very common and their distribution is irregular. The main part of the Fe-oxide alteration zone does not appear to be mineralized and bulk sampling did not improve the results of conventional sampling techniques. A batch of 200 surface samples only contained 32 samples that assayed better than 0.02 oz/ton, and most of these are closely related to the old workings.

At the Santa Fe area the backhoe bulk samples indicated several locations with highly anomalous gold mineralization. The minus 1/8" material of 6 of the 12 samples assayed better than 0.02 oz/ton with 8 samples in excess of 0.10 oz/ton. A 20 ft vertical profile in the center of the Santa Fe area averaged 0.372 oz/ton (minus 1/8" material). This mineralized section could be followed for about 100 feet

along strike. Mineralization is caused by tiny siliceous Fe-oxide seams. The minus 1/8" screened fraction represents about 15% of the total material, but recalculation of the assays of the fine fraction to whole rock values posed problems due to insufficient head assays. A set of 200 conventional whole rook samples collected over the full extent of the Fe-alteration zones showed 86 samples with assays over 0.02 oz/ton, with only 6 over 0.10 oz/ton.

The 1988 program failed to delineate any large, low-grade reserves on the property. Small areas with significant values occur in narrow zones, 100 to 200 long, but they do not appear to be common and their distribution is irregular.

CONCLUSIONS

Gold mineralization in the Blackhawk Canyon area is restricted to the Furnace Formation marbles. Geological and mineralogical data suggest that the mineralization is controlled by a multistage process. The primary mineralization is associated with gold-silverpyrite-base metal sulfide-quartz veins and replacement bodies and also with sericitized igneous dikes. One or more later events caused almost complete oxidation of the sulfides and widespread mobility of Fe-oxides along with limited remobilization of gold. The oxidation was probably coincident with the Santa Fe thrusting event and concomitant brecciation of the marble host. Epithermal fluids, associated with the thrusting, caused widespread argillic alteration but do not appear to have introduced any gold. Shearing dismembered the old veins, lenses and dikes and probable facilitated the circulation of oxidizing fluids. Precipitation of the Fe-oxides in the brecciated marbles resulted in the formation the extensive Fe-oxide alteration zones.

The original mineralization responsible for the auriferous quartz-sulfide veins is related to C02-bearing saline aqueous fluids with a temperature of about 300 degrees C. This suggests a distal skarn-type mineralization related to the emplacement of porphyry dikes or a larger non-exposed intrusive, tectonically displaced from the marbles by the late stage thrusting event.

The 1988 exploration program in the Fe-oxide altered areas outlined small zones with promising gold contents but was unable to identify a low-grade bulk-mineable target. The main part of the Fe-oxide alteration zone does not appear to be mineralized to any significant extent. Bulk sampling essentially confirmed results of conventional sampling programs.

The model proposed for Blackhawk downplays the importance of the regional Santa Fe thrust zone as a site of precious metal mineralization. On a regional scale, replacement mantos in Furnace Formation marbles may be favorable exploration targets for precious metal deposits, especially in areas of abundant igneous dike activity.

ACKNOWLEDGMENTS

We thank Amerigold Inc., and especially Roger Ames, for invaluable assistance and cooperation during our field campaign at Blackhawk.

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CRUSTAL HABITAT OF PRECIOUS METAL MINERALIZATION WITHIN THE EXTENDED TERRANE OF SOUTHERN CALIFORNIA AND WESTERN ARIZONA

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Middle Tertiary extension occurred throughout most of the southwestern United States and was directly and indirectly responsible for localizing many of the mineral deposits within this region. Recognition of the crustal scale of this extension and its different manifestations has helped define a unifying theme to the genesis of many mineral deposits in California and Arizona. Many of these deposits are localized within the complex high- and low-angle normal fault systems that are associated with the extensional, or detachment, system (Figure 1). Major gold deposits like Picacho and Mesquite appear to occur at the highest structural level of the detachment system, whereas copper-iron systems appear to form in a deeper structural environment. This highest structural level where the gold deposits are located occurs on the upper side of tilted crustal slabs produced during the extension. Recognition of the such tilted crustal slabs and their geometries thus becomes very important for determining where exploration should be concentrated to find similar deposits.

Tilted crustal slabs within southern California and western Arizona are most easily identified from the locations of their basal units. The Pelona-Orocopia-Rand Schist or thick sequences of mid-Tertiary mylonitic rocks compose the basal unit in most currently recognized tilted crustal slabs. The Pelona-Orocopia-Rand Schist, in particular, is a major guide to the tilted slabs because this unit formed at middle-crustal level in late Mesozoic time, but is exposed as large antiformal culminations within many ranges (Figure 2). Exposure of this unit largely occurred by large-scale normal faulting that segmented the upper crust in Tertiary time and tilted the upper crust onto its side. The schist and its overlying gneissic rocks were thus tilted to their current exposures and mid-Tertiary basins were formed in the lows between tilted blocks. Basins such as that northeast of Mesquite in Milpitas Wash and those northeast of the Orocopia-Sierra Pelona-Mt. Abel regions (Diligencia-Soledad-Cuyama basins) record both the timing and geometry of slab tilting during extension. Numerous detachment faults that are directly responsible for tilting over the upper crust, exposing the Pelona-Orocopia Schist, shattering the upper-crustal gneisses, and producing the structural preparation for localization of the ore deposits can currently be identified. However, many more such faults are probably exposed, but just not yet recognized, making the potential for discovery of new world-class gold deposits very great.

The locations of most of these future deposits is thought to be beneath the alluvial cover on the margins of ranges, rather than within the exposed rocks of the ranges, themselves, which have been the traditional focus of most minerals exploration. Because the gold mineralization occurs in rocks that have been intensely broken, they erode away very easily, producing placer deposits that could be used as a guide back to the source area,

which will eventually be covered by alluvium. The solid rocks protruding from the alluvium are preserved because of their general lack of shattering and associated lack of mineralization. Many tilted mid-Tertiary volcanic units record a portion of the extension, but appear to be largely post-mineralization. These barren volcanic rocks thus also serve to hide the underlying shattered and mineralized gneissic and granitic rocks.

Figure 1. Complex extension of a small-scale stratigraphic section from the southern Whipple Mountains, California. The geometry of the faults in this outcrop example mirrors the geometry of the faults on a much larger scale, where the complexity and interrelationship of faults is much more difficult to discern. As the rock units are tilted over, the normal faults tilt to lower dips and become low-angle normal, or detachment, faults. Mineralization is localized within the shatter zones produced by the intensely developed faulting. Solid blocks would represent mountain ranges and highly faulted areas would be the intervening valleys. Precious metal mineralization such as at Mesquite and Picacho appears to be localized within the highest structural level of this extensional system.

Our changing understanding of the genesis of such deposits also requires a change in understanding of where mineral deposits might be located and how federal and state lands should be managed to recognize the potential for these extension-related deposits. Because these deposits are largely or completely buried, they have not been found by prospectors or geologists wandering over the exposed outcrops. The exposed ranges do offer the geologic clues to help find these deposits, but may not contain the deposits themselves. Land use planning and minerals assessment procedures may need some reexamination to incorporate the implications of Mesquite and Picacho type deposits for the most appropriate use of state and federal lands.

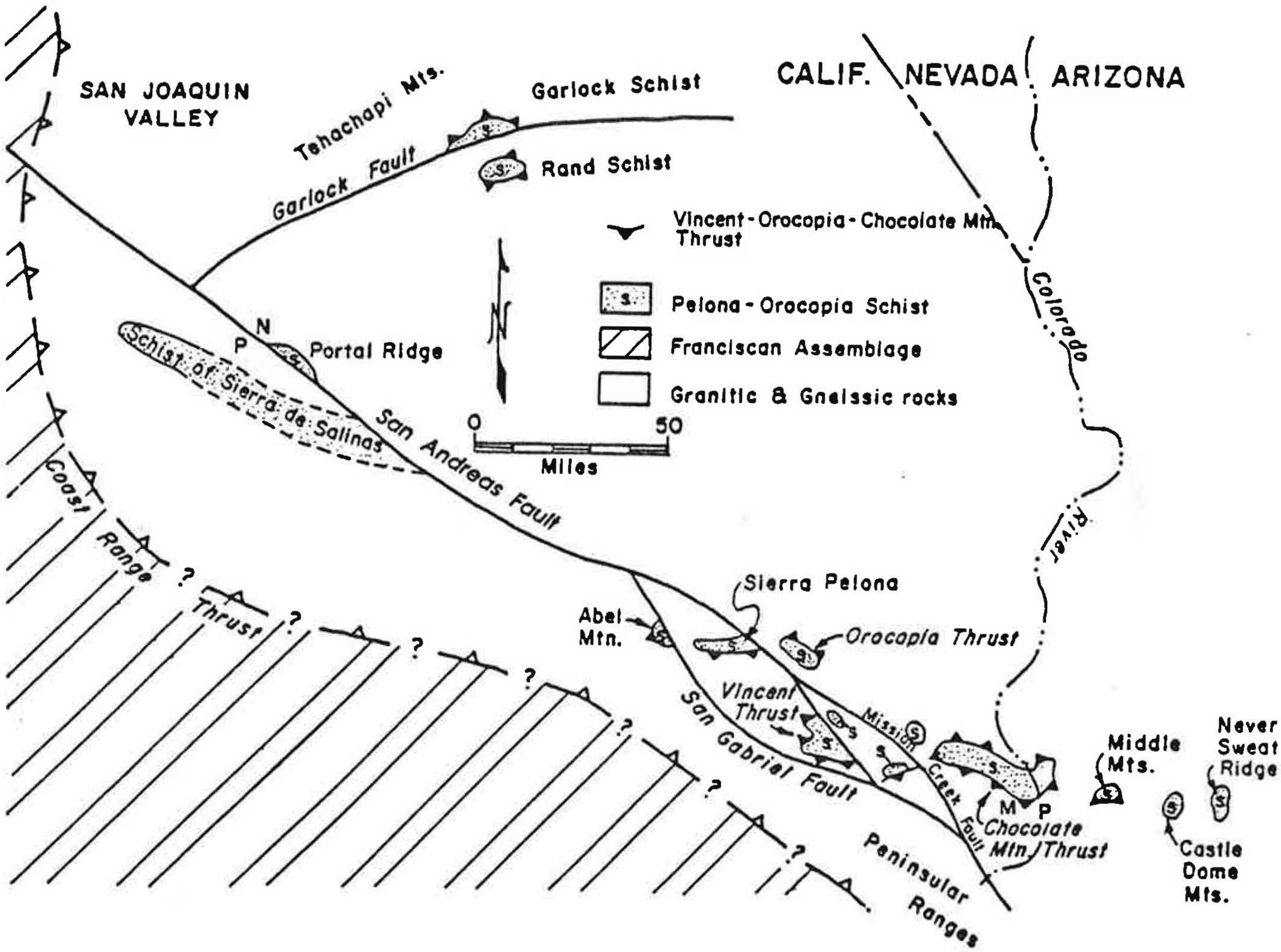

Figure 2. Pre-San Andreas reconstruction of southern California after John Dillon (1975, UCSB dissertation) showing the locations of the exposures of Pelona-Orocopia-Rand schist. Most of the exposures of these rock units now mark the base of large-scale tilted crustal slabs. Along with the thick sequences of Tertiary mylonitic rocks exposed in some of the metamorphic core complexes, the Pelona-Orocopia schist offers the easiest way of identifying the major tilted slabs in southern California and western Arizona. Large-tonnage, low-grade gold deposits such as Mesquite (M) and Picacho (P) are localized on the upper portion of these tilted crustal slabs.

The Mesquite and Picacho Gold Mines: Epithermal Mineralization Localized Within Tertiary Extensional Deformation

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INTRODUCTION

Exploration for large-tonnage, low-grade gold deposits has been strongly stimulated by the opening of the Picacho and Mesquite mines in southeasternmost California. These two deposits form the focus of this field trip and should provide the participants with an overall view of the mines themselves, as well as the geologic setting in which they occur. The Mesquite deposit is operated by Gold Fields Mining Corporation and has been officially in production since February 1986. Little previous production had occurred on the Mesquite claims, although a significant number of small workings dot nearly all the outcrops of gneissic rocks protruding from the alluvium. The Picacho mine is currently operated by Chemgold, Inc., and has had a long history of sporadic development dating back more than a century. Near the turn of the century, Picacho was a major underground mine, which closed in 1908 because of a major mechanical failure at its 450-ton mill (Odens, 1973). Both Mesquite and Picacho are largely within shattered Jurassic gneiss and represent a different type of ore deposit than was widely recognized before these mines came into production. Their exact genesis is still not completely known, but both appear to have had a similar origin. This field trip is designed to point out the similarities between the deposits, information that should help those seeking to find similar gold deposits.

GENERAL STRUCTURAL SETTING

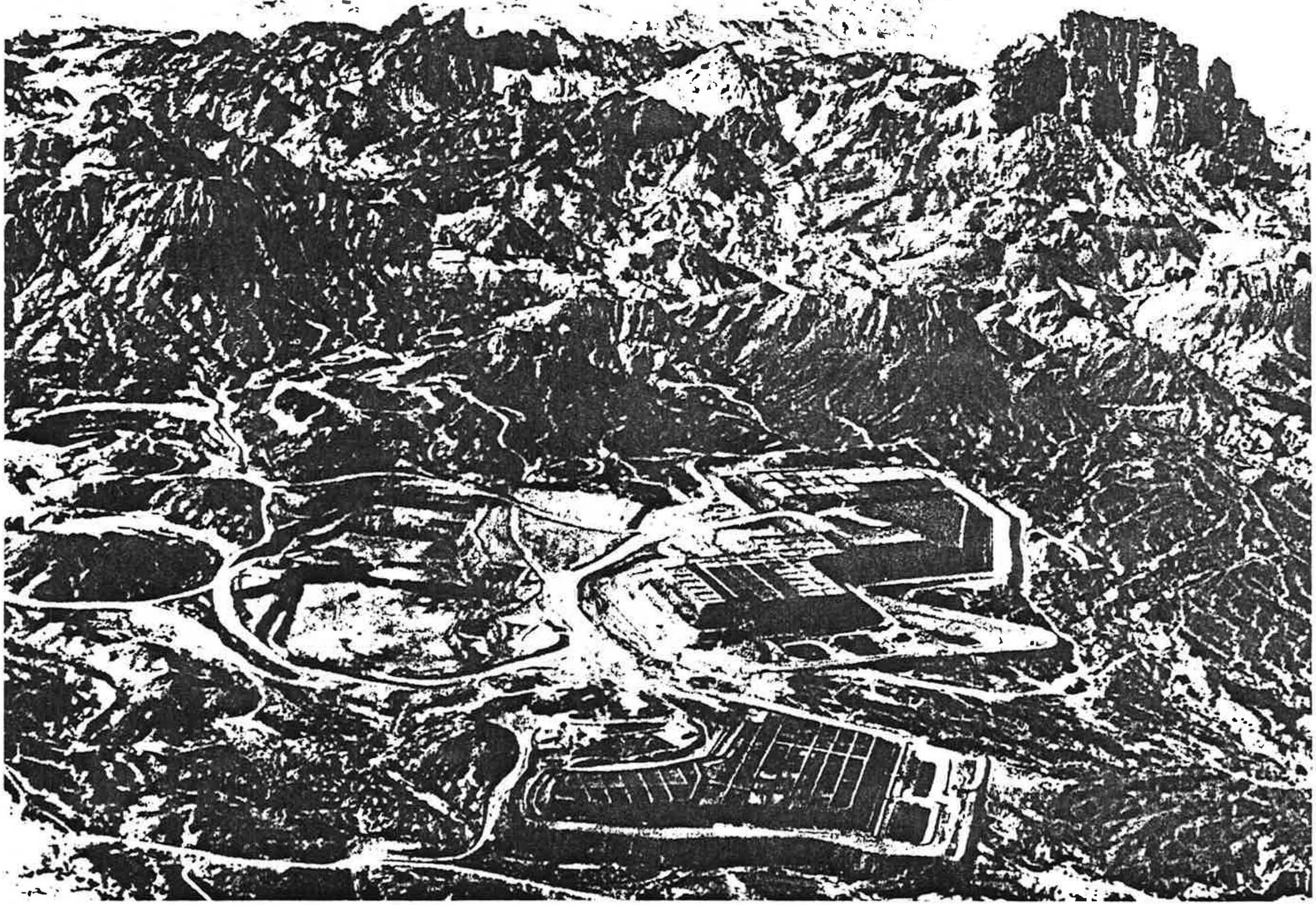
Both deposits occur along the southwestern limb of the regional Chocolate Mountains antiform (Figure 1), an elongate structure that exposes the Orocopia Schist in western Arizona and southeastern California. The early Mesozoic Orocopia Schist represents the structurally deepest recognized basement within southern California and has long been a key to unravelling the complex history of the region. Offset of the Orocopia Schist and some of the distinctive overlying gneisses formed part of the early basis for proving major offset on the San Andreas fault (e.g., Crowell and Walker, 1962). Work by UCSB Ph.D. students Bruce Crowe, John Dillon, Gordon Haxel, and Dick Tosdal (all working with John Crowell) has provided the basis for much of our understanding of the overall geologic history of the region. Their work on the Mesozoic tectonics of the region, in particular, has formed the basis for most of what is known of the Mesozoic magmatism and deformation in the area (Haxel and Dillon, 1978; Haxel and others, 1985; Haxel and Tosdal, 1986). Major regional synthesis of the magmatic and deformational development of this region has also been done by Stan Keith (Keith, 1986; Keith and Wilt, 1986), providing many thought-provoking alternatives to previous ideas.

Overprinted on the Mesozoic magmatic and deformation history is crustal-scale extension of mid-Tertiary age. One component of this extensional system is a regionally developed low-angle normal fault, or detachment fault. A detachment fault is well exposed just north of the Picacho mine (Frost and others, 1986) and was reported in some of the early workings in the Picacho open pit (Wilkins, 1984). The genetic relationship between detachment faulting and gold mineralization has sparked much recent work on the region, as well as in the vicinity of other detachment faults in the western United States. Mineralization within the overall detachment system appears to occur within the zone of shattering near the low-angle fault, along the high-angle normal faults that feed downward into the detachment fault, and within placers and talus breccias produced by the erosion of the deposits.

How the Picacho and Mesquite mines fit into the combined history of Mesozoic magmatism-deformation and mid-Tertiary extension will be the theme of this trip. Most observers of the geological setting related to the gold mineralization at Mesquite and Picacho are generally impressed with the following major features:

1) intense deformation of the host rock,
2) intense cataclasis associated with this deformation,
3) restriction of the mineralization to metamorphic rocks,
4) favorable host dominance by the more quartzo-feldspathic units,
5) lack of significant veining and silicification,
6) relatively minor lteration of the host rock, and
7) persistence of gold mineralization even in relatively unaltered gneiss.

As the gold potential at Mesquite and Picacho were uncovered by mining, several different genetic models for the mineralization were proposed, based on differing experiences, biases, and interpretations of diverse data. The most widely proposed models include the following:



Frontispiece: Oblique aerial view of the Picacho mine showing the multiple pits, which are the disrupted pieces of a once continuous orebody. Volcanic rocks in the background overlie the deposit and show little of the detachment-related deformatio

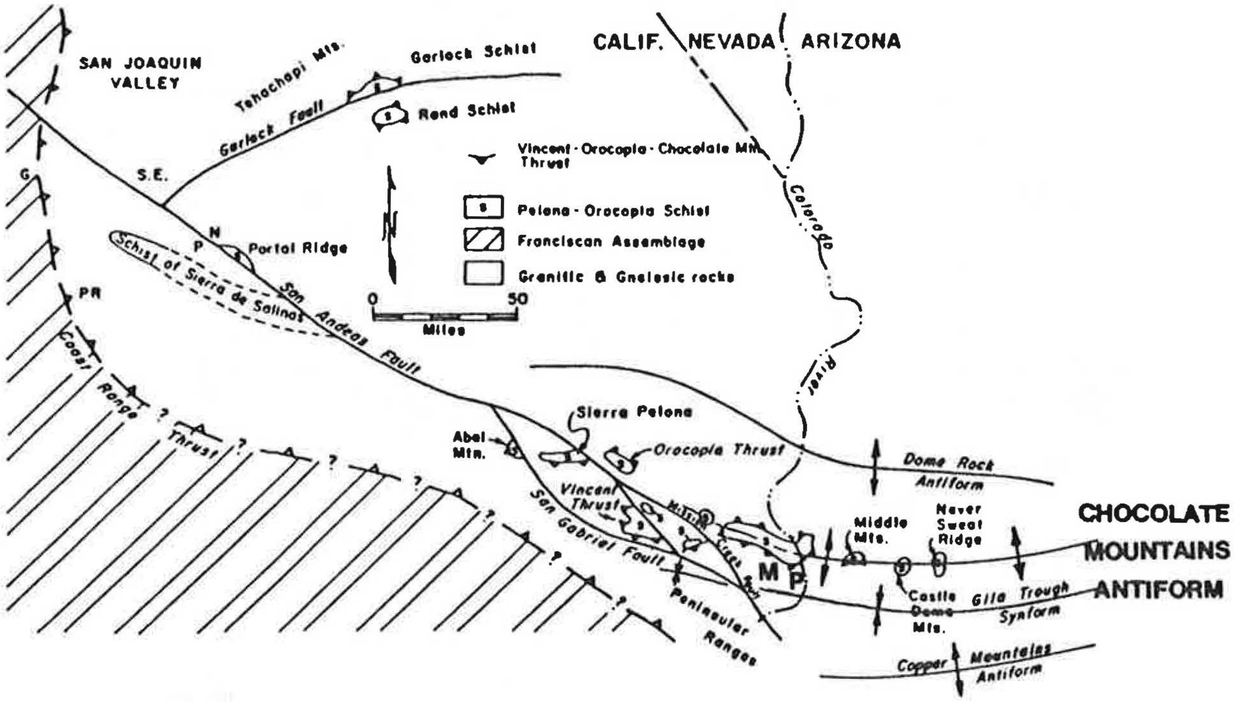


Figure 1. Regional geologic map of southern California and western Arizona in a pre-San Andreas reconstruction by Dillon (1975). Large-scale antiforms and synforms produced during mid-Tertiary crustal extension are drawn on Dillon's base map. Both the Mesquite mine (M) and Picacho mine (P) are on the southwestern limb of the major Chocolate Mountains regional antiform.

1) a syngenetic model related to exhalative processes that predated metamorphism. Such a syngenetic model seemed especially attractive because of the low dip of the deposit, similar to that in the apparently Precambrian host gneisses.
2) a Cretaceous - Paleocene structural model related to the formation of the Chocolate Mountains thrust, which served as a hydrothermal conduit that fed the fluid-receptive, upper-plate gneisses. The proximity of the thrust, the strong structural control of mineralization, and the similar shattered character of some mapped occurrences of the thrust made this interpretation attractive.
3) a magmatic source related to hydrothermal solutions derived from a felsic (peraluminous) intrusive body in the vicinity of the mineralization. The regional association of peraluminous rocks with gold mineralization made this interpretation promising as the original source for the gold, if not for the current mineralization.
4) a detachment-fault model in which crustal extension produced the ground preparation for localizing the ore fluids and continued to deform, progressively offsetting the early-formed faults and mineralization. The shattered character of the ore and proximity of the detachment fault at Picacho made this interpretation seem inviting.
5) a hot-spring model related to the early development of the San Andreas transform or to volcano-plutonic, heat-driven fluid. The proximity of the San Andreas to the Mesquite mine and the nature of mineralizing fluids in the Salton Sea geothermal wells made this interpretation seem appealing.

All of the above models have been variously advocated by different individuals on the basis of a variety of data. As more work has been done on these deposits, several of the above hypotheses have lost their attractiveness. A goal of this trip will be to elucidate the appropriate information that will allow each participant to see what is currently known about these deposits, their genesis, and their subsequent deformation.

DAY ONE: MESQUITE MINE AND ITS GEOLOGIC SETTING

Leave Yuma and drive west on Interstate 8 to the Ogilby Road turnoff. Continue north on the Ogilby Road past the Cargo Muchacho Mountains to the intersection with State Highway(SH)78. Pull off the highway onto the dirt road that is the northward continuation of the Ogilby Road. From this vantage point, the overall form of the Chocolate Mountains and the setting of the Mesquite and Picacho deposits can be seen.

STOP 1: REGIONAL STRUCTURAL SETTING

The high portion of the Chocolate Mountains is composed of the rather uniformly dark-colored Orocopia Schist, which is deformed into an elongate NW-SE-trending antiform. From this view point, the short axis of the antiform is visible with dips of the foliation to the SW and NE. At the center of the antiform is the mid-Tertiary Mount Barrow granodiorite, which is well exposed just to the north (Gables Road), especially in morning light. Most of the low, maroon-colored rocks to the west of this vantage point are volcanic rocks whose genetic relationship to the Mount Barrow granodiorite is not well known. However, their K-Ar ages are nearly the same, and it was the feeling of Dillon (1975) that the volcanics represented a caldera sequence intruded by its own plutonic

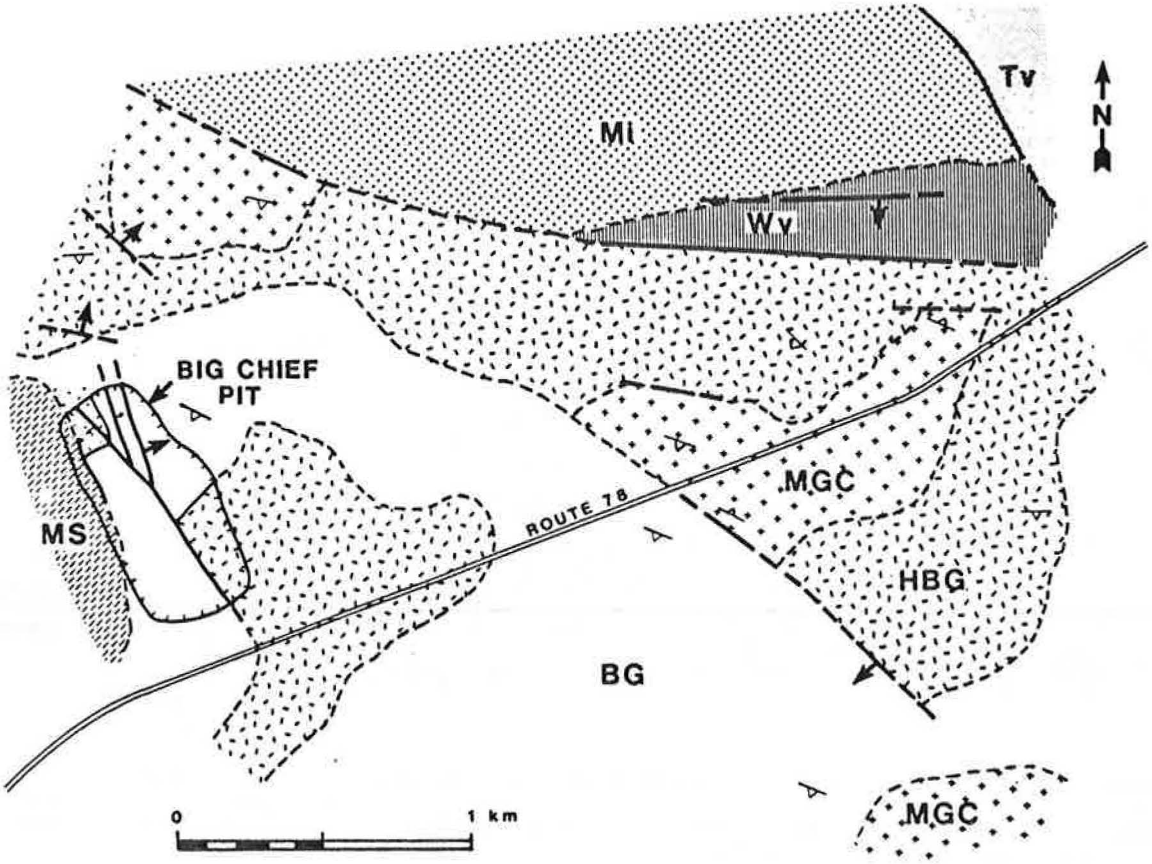


Figure 2. Large-scale geologic map of the Mesquite mine area as deduced from geologic mapping and extensive drilling (from Manske and others, 1987). Outline of the Big Chief pit is shown; several other pits are planned for this same area. Ore deposits occur largely within Jurassic gneiss with minor Cretaceous leucogranite. Abbreviations: BG = Biotite Gneiss, HBG = Hornblende-Biotite Gneiss, MS = Muscovite Schist, MGC = Mafic Gneiss Complex, Wv = Winterhaven Formation, Mi = Mesozoic intrusive rocks, and Tv = Tertiary volcanic rocks. From: Manske and others (1987).

root. These volcanic and interbedded sedimentary rocks overlie the relatively low-relief gneisses that sit structurally above the Orocopia Schist. The contact between the schist and the gneiss is defined as the Chocolate Mountains thrust, a regional fault system that appears to have moved in Late Cretaceous time (87-74 Ma) based on work done in the San Gabriel Mountains (Haxel and others, 1985).

The dip of the thrust has little relationship to its orientation during Mesozoic deformation; it has been tilted to its present position by deformation related to mid-Tertiary extension. The intermediate to steep dip of both the thrust and foliation within the Orocopia Schist indicates that major, postthrust deformation has affected this terrane. In contrast, the volcanic rocks visible along the road and forming the low foothills to the range are only gently tilted, indicating that a significant amount of the postthrust deformation was over prior to the extrusion of these late Oligocene-early Miocene volcanic rocks (Dillon, 1975; Crowe, 1978). Evidence of a similar deformational history is apparent over much of SE California and SW Arizona along the flanks of the Chocolate Mountains antiform (Figure 1). Similar geometries are also present on the west side of the San Andreas fault system, which has offset the regional antiforms and synforms, beginning in late Miocene time.

The change from regional extension to transform motion associated with the San Andreas system was marked by the extrusion of black basalts such as those that form most of the Black Mesa skyline to the SE. Regionally, these flows yield similar ages of about 12 Ma and generally have low strontium initial isotopic ratios, indicating a large component derived from mantle sources. North-south feeder dikes characterize this system, indicating a major change in stress orientation at this time. Microplate rotations, such as those described just to the north by Carter and others (1987), also characterize the region during this time period.

Proceed west along SH 78 to the Mesquite mine for Stop 2. Along the drive from Stop 1 to the mine, the Tertiary andesites occupy most of the area on either side of the road. These deposits actually form only a thin veneer over the gneissic rocks that host the mineralization at Mesquite and Picacho. When the mine comes into view, note the low outcrops north of the road---they are good examples of the various gneissic units in the Mesquite mine. The pseudostratigraphic section that forms the deposit can be seen along the road (Figure 2), with a basal mafic complex overlain by biotite gneiss, hornblende-biotite gneiss, and muscovite schist, all of which are intruded by several generations of aplite, pegmatite, and leucogranite.

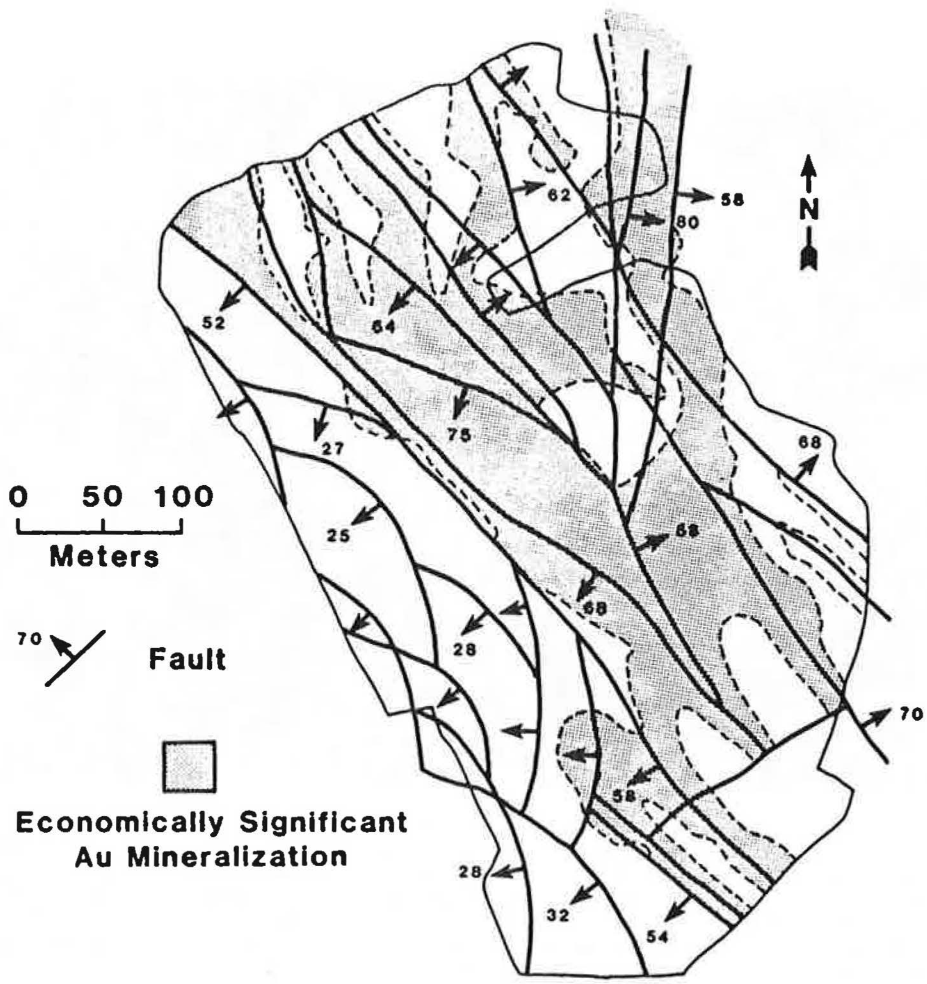


Figure 3. Map of the Big Chief pit showing the relationship between large-scale faults and gold mineralization. Faults on the southwest side of the pit are scoop shaped and appear to be related to gravitational motion toward the Salton Trough, significantly after mineralization occurred. These low-angle faults are unmineralized and cut the high-angle faults, which localize the most significant gold mineralization. Modified from Willis and Holm (1987).

These gneisses generally dip to the SW off the Chocolate Mountains antiform. They are repeated by several major normal faults that dip to the NE, thus tilting the gneisses back toward the Salton Trough. On a large scale, the entire Chocolate Mountains are tilted to the SW, probably as a response to crustal-scale extension. Most of the gneissic rocks that host the mineralization are on the SW limb of the antiform, with the deeper crustal Orocopia Schist and postdetachment volcanic rocks forming much of the NE limb of the antiform.

STOP 2: MESQUITE MINE OVERLOOK

At the northeastern corner of the pit, the overall character of the deposit can be seen. Most of the gneissic rocks dip to the SW and are cut by numerous generations of normal faults (Figure 3). These faults offset the rocks exposed on the NE side of the pit to the NE and the rocks on the SW side to the SW, producing a central horst and an adjoining series of half grabens. The high-angle normal faults strike N40°-50° W and are relatively steep and planar on the scale of the pit. In detail, the fault surfaces are highly convoluted because of the complexity of the faulting and their obvious development through a significant amount of progressive deformation. Mineralization is strongly localized along these high-angle faults (Figure 3), indicating the profound structural control that has localized the deposit.

Cutting these high-angle faults are a number of spoon-shaped, low-angle faults, which place unmineralized muscovite schist over the mineralized gneisses. The muscovite schist is overlain by the mid-Miocene Bear Canyon fanglomerate and interbedded dark basalt flows. These sands and gravels were deposited unconformably on the muscovite schist, as well as on the mineralized gneiss.

Tilting of these sands along spoon-shaped normal faults indicates that at least some of the deformation that put the muscovite schist on the gneisses is postdetachment-related extension in age. Because the Bear Canyon and overlying basalts were deposited after the mid-Tertiary extension, their deformation is probably related to gravitational motion into the Salton Trough. The scoop-shaped character of the faults and

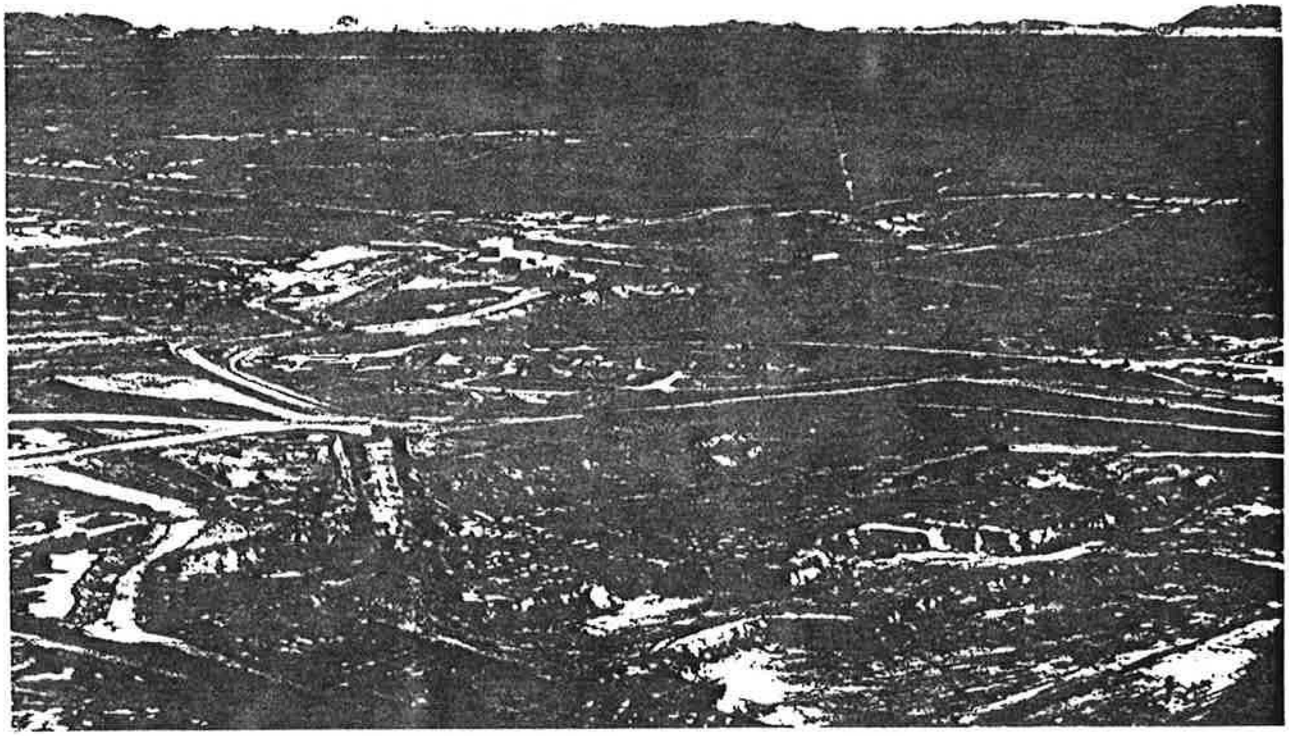


Figure 4. Oblique aerial view of the Big Chief pit area in the Fall of 1985. Pit is enormously larger now, indicating the speed at which mining is taking place. Picacho Peak can be seen on the left skyline, with almost completely covered area in between the two deposits. Other deposits such as Mesquite and Picacho probably exist between the two, but are hidden. Lack of major outcrops in the area is a result of the highly shattered nature of the rock. Similar areas of low relief produced by the erosion of shattered crystalline rocks can be a major guide to finding other such deposits, in contrast to studying the unmineralized, but more highly resistant, rocks exposed in the range itself.

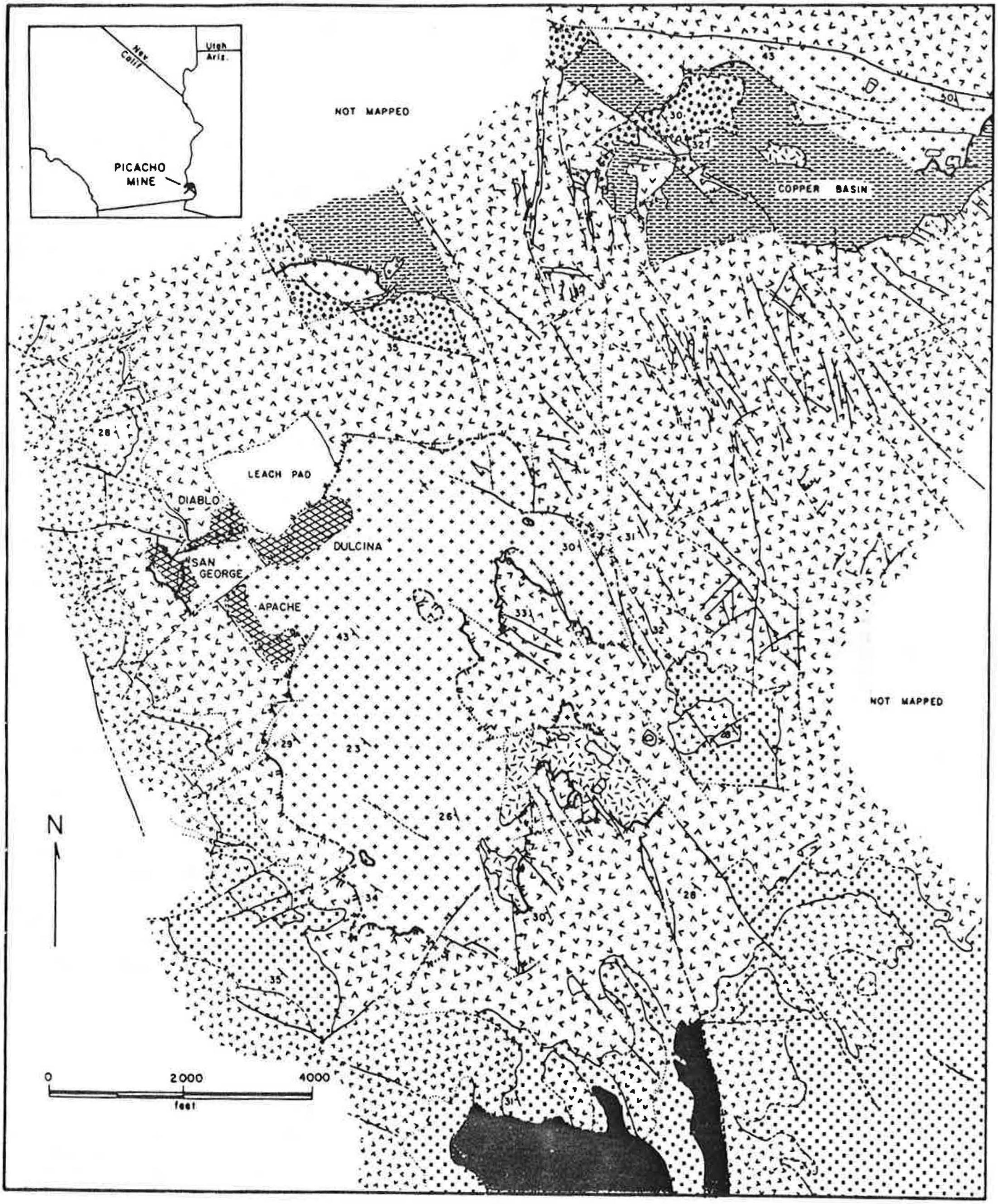
the abundant down-dip striae on the fault surfaces indicate that these faults are almost entirely normal faults, rather than strike-slip faults related to the San Andreas system itself. Abundant strike-slip striae and mullion structures are present on zeolitized surfaces within the Bear Canyon sands, but are mostly along faults striking NE-SW, perpendicular to the major normal faults. These near-vertical faults appear to have acted as tear faults accommodating differential motion of the landslidelike fault blocks.

STOP 3: MINERALIZATION IN THE BIG CHIEF PIT

Drive to the ore faces on several benches for in-depth scrutiny of the general character of the mineralization within variations of biotite gneiss, hornblende-biotite gneiss, pegmatites, and leucogranite. The leucogranite, which contains garnet and tourmaline, appeared to be a fairly major body during the initial development stages of the pit, making it attractive as the cause for the formation of the deposit (S. Keith, pers. commun., 1986). Further mining has shown that the leucogranite is probably sill-like in form and is much less conspicuous in the pit as a major rock type. The unit has yielded a 38 Ma K-Ar age (Willis and Holm, 1987). However, a Cretaceous concordant U/Pb zircon age has been obtained on the unit (Frost, 1987), indicating a disturbance in the K-Ar system.

Regional resetting of the K-Ar system within the metamorphic rocks of the southern Chocolate Mountains occurred at about 60 - 70 Ma (Frost and Martin, 1983a), an age similar to the 58 Ma K-Ar age on the muscovite schist (Manske and others, 1987). The 38 Ma age on mineralized rock suggests that mineralization occurred during the Tertiary and partially to completely reset the ages of formation and metamorphism of the various rocks to an unknown degree. Further geochronologic work is in progress to determine more completely the age and duration of mineralization.

Mineralization is "disseminated" in that the ore is along innumerable fractures, gouge zones, and breccia zones, as well as within apparently unbroken rock. Alteration varies from appearing intense, mostly because of a bleaching effect on the biotite gneiss, to appearing very subtle to absent. Detailed work on the mineralization by Manske and others (1987) has demonstrated that (1) the ore fluids were at temperatures of 210°- 230°C, (2) salinities were 1% NaCl equivalent, (3) boiling appears to have occurred during precipitation because of the presence of liquid and vapor-phase fluid inclusions, (4) gold is associated with pyrite and, to a much lesser degree, other sulphides, although most of the ore is highly oxidized, and (5) depths of formation are 300 m and less. These studies, together with the detailed pit mapping of


Utah
Ariz.
Nev.
Calif.
PICACHO
MINE
NOT MAPPED
COPPER BASIN
LEACH PAD
DIABLO
DULCINA
SAN
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APACHE
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N
0
2000
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Gerry Willis (Willis and Holm, 1987) that shows the relationship between faulting and gold mineralization (Figure 3), very nicely define Mesquite as an epithermal deposit. Circulation of meteoric water through the structurally prepared rock appears to be a primary cause for localizing the deposit. Where the gold originated from and what the thermal regime driving the fluid system was are still major unknowns that are being actively investigated.

STOP 4: MINERALIZATION IN THE VISTA PIT AREA

Proceed across Highway 78 to the desert pavement just opposite the Big Chief pit (Figure 4), an area that is the proposed site for the Vista pit. This stop will emphasize the subtlety of the surface exposures of Mesquite-type deposits. Many of the low hills of gneiss in this area are ore or are underlain by ore. Most of the outcrops are pockmarked by old workings, indicating that the old-timers recognized the pervasiveness of the mineralization, but did not understand it. The bottoms of many of the small washes expose outcrops of the brittlely deformed gneisses and demonstrate the thinness of the alluvial veneer that has hidden these deposits from previous development. The low-relief character of the broken gneisses appears to be a definite characteristic of these deposits. If time allows, a short traverse through the various gneissic rocks and associated fault structures will be undertaken. Return to Yuma.

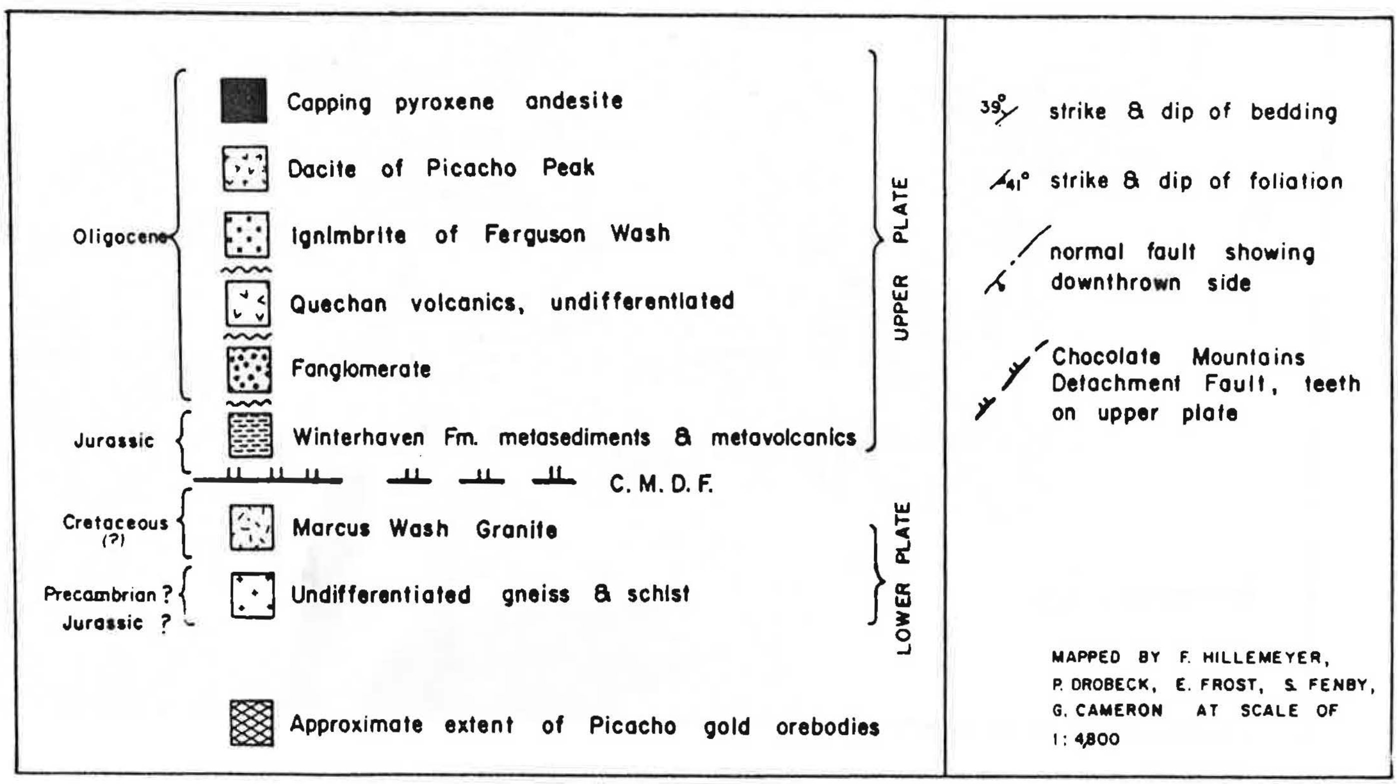
DAY TWO: PICACHO MINE AND DETACHMENT FAULT

Leave Yuma going west toward Winterhaven, just across the Colorado River. Turn right on County Road S24 and follow the signs toward Picacho State Recreation Area. Cross the All American canal and proceed on dirt road toward Picacho Peak and Picacho recreation area. Stop on low hill just over Picacho Pass (15.9 miles from Colorado River) for Picacho overview.

STOP 1: PICACHO BASIN OVERLOOK

From this vantage point, it is possible to see many of the tectonic elements of the southern Picacho region. In the volcanic cliffs that form the western margin of the Picacho basin, one can see a general stratigraphic section composed of dark, resistant flow units, interbedded white tuff, and other assorted volcanic units. The volcanic rocks in this region were mapped by Crowe (1978), who interpreted the high-angle faults that cut the volcanic section as recording the early development (Oligocene) of the Basin and Range Province. The multiple normal faults offset the volcanic section numerous times, repeating the relatively thin section over and over across the entire southern Chocolate and neighboring Trigo Mountains. The volcanic section is tilted about 20° or less, whereas the fanglomerates and other sedimentary and volcanic rocks that underlie the cliff-forming volcanic sequence are tilted significantly more, and are even overturned in places. Much of the extensional deformation, therefore, occurred prior to deposition of the widespread volcanic section, which is so prominent in the Picacho basin. Postdetachment deformation in the area has produced variable deformation along the volcanic-prevolcanic unconformity, making the relationship of the volcanic rocks to detachment

Figure 5. Geologic map and legend of the Picacho mine area from Drobeck and others (1986). Several pits that make up the Picacho mine are shown within the Jurassic(?) gneiss. Excellent exposures of the detachment fault are present in the structural window just north of the deposit. Other exposures have been and are being mined from within the Picacho pits. Mid-Tertiary volcanic units cover the deposit and the detachment fault and show little of the detachment-related deformation.



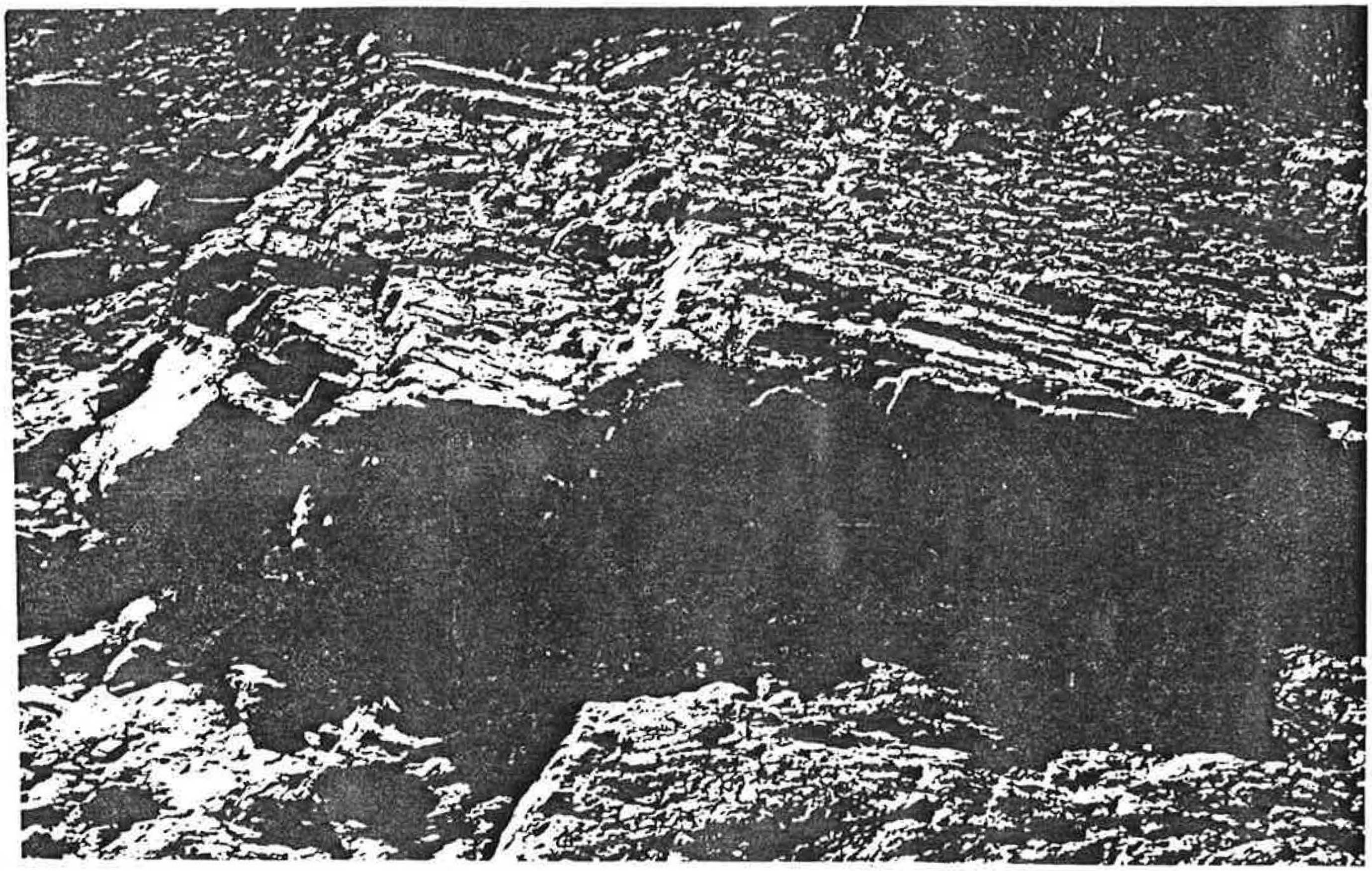


Figure 6. Small-scale view of a portion of the microbreccia ledge north of the Picacho mine. Area in the sunshine in the upper half of the photo is the fault surface. Small-scale normal faults have offset the detachment fault, progressively dropping it down to the south. Larger normal faults in the area follow the same geometry, dropping the detachment fault down from these exposures to those at the mine.

faulting more difficult to decipher. This is especially true where the volcanic rocks overlie the exhumed detachment fault or the shattered and eroded lower-plate rocks.

These volcanics uniformly contain almost no mineralization and serve to hide the underlying extensional deformation and associated ore deposits. The volcanics are involved in major postmineralization faulting that has segmented many of the known ore bodies, such as those exposed in the Picacho mine. Some of these postdetachment normal faults have offsets of several hundred meters, significantly disrupting the overall detachment-related deformation and mineralization. Most of the faults have offsets measured in meters to tens of meters, so that finding and mining offset pieces of exposed areas of mineralization is possible.

STOP 2: PICACHO MINE

Continue down the Picacho road and enter the Picacho mine; proceed to the top of the Dulcina pit (Figure 5) for an overview of the Picacho mine and its operations. Detailed descriptions of the history and mineralization at Picacho can be found in Van Nort and Harris (1984), Drobeck and others (1986), and Liebler (1986). Mineralization occurs in metaplutonic gneiss, which was once thought to be Precambrian, but which now appears to be Jurassic (Tosdal, 1986). These gneisses occur above the Orocopia Schist, putting the structural setting of the mine well above the Chocolate Mountains thrust. Several small leucocratic intrusions occur within the gneiss and may be of various ages.

The original Picacho orebody was tabular in shape, but has now been segmented into at least five major pieces by postmineralization normal faulting (Figure 5). Ore grades occur in highly broken rock, making it possible to simply dump the blasted rock directly on the leach pads with no intervening crushing or agglomeration (Mike Fitzgerald, pers. commun., 1987). Most of the ore is highly oxidized, staining the Jurassic(?) gneiss a red or maroon color. At the base of the Dulcina pit (as of February 1987), the unoxidized gneiss is exposed beneath the oxidized ore across a major low-angle fault. Rocks on either side of the fault are highly deformed in a very brittle fashion. This fault is probably appropriately considered to be a detachment fault, although other subparallel detachment faults are also present in the area.

This low-angle deformation has been offset on the postdetachment and largely postmineralization normal faults (Figure 5). Offset on some of these high-angle faults was also clearly postextrusion of the Picacho volcanics because these volcanic units are variably disrupted throughout the region. Clasts of the mineralized gneiss and postdetachment volcanic rocks are

intermixed in several talus breccias that formed from spalling off these postdetachment normal faults. Some of the talus breccias compose significant bodies of ore and also made deciphering the mine geology rather perplexing during early studies of the ore deposit.

Mineralization at Picacho is distinctly epithermal in character, with the ore grades related to the degree of shattering more than any other single factor. Euhedral pyrite cubes in a breccia matrix of gneiss further indicate that the structural preparation of the rock controlled the localization of hydrothermal fluids. The more leucocratic units, such as the pegmatites and Marcus-Wash(?)-type rocks, shatter more than the gneiss and form better host rocks. The leucocratic bodies appear to be related to mineralization by their ability to fracture rather than by their chemistry or original contribution of mineralizing fluids.

Fluid-inclusion studies of the Picacho ore by Liebler (Drobeck and others, 1986; Liebler, 1986) on quartz thought to be associated with mineralization indicate temperatures of 210°- 230° C and very low salinities, much like those at Mesquite (Manske and others, 1987). Percolation of meteoric water through these rocks requires that fractures and cracks be open, suggesting a very shallow character of the mineralization. As such, mineralization like that at Picacho may characterize the upper portion of a detachment system, rather than deeper levels where more gold-barren systems are more characteristic.

Sucking of the fluids into the rock during earthquake motion on the normal-fault system in a fashion as suggested by Sibson (Sibson, 1986, 1987) forms a very attractive way of localizing ore fluids in the fault zones. According to Sibson's detailed studies of fluid-fault interaction in other parts of the world, earthquake rupture on the faults may be the driving mechanism for circulating fluids through extensional jogs within the overall deformational system. Continued work on the details of fault geometries and mineralizing systems may provide powerful insight into the genesis of these and other ore deposits.

STOP 3: PICACHO MINE DETACHMENT FAULT

Continue driving north on Picacho Road for 1 mile to the intersection of Little Picacho Wash with the road and park off the side of the road. Stop at the entrance to Little Picacho Wash and examine the Winterhaven Formation, which makes up both sides of the wash. The Winterhaven consists of metavolcanic, volcanoclastic, and metasedimentary rocks that are largely phyllitic in character. Elsewhere within the Picacho basin, the Winterhaven contains a clean quartzite that may be correlative with the Aztec Sandstone, making the unit Early Jurassic, or perhaps Late Triassic in age (Frost and Martin, 1983b).

A large normal fault drops the postmineralization volcanic rocks down against the Winterhaven at the entrance to the wash. The fault itself can be seen in the canyon wall just north of the entrance into Little Picacho Wash. Walking up the wash, one can see many other normal faults that are well exposed in the canyon wall. These normal faults offset and tilt the Winterhaven innumerable times, repeating distinctive metavolcanic and metaconglomeratic units over and over. The style of normal faulting visible here on a small scale seems characteristic of the style of normal faulting on a much wider scale within the entire detachment terrane. The detachment fault is only a few meters to tens of meters below the wash here, making this deformation typical of the lowermost portion of the upper plate. The intensity of faulting increases as one progresses up the wash, i.e., as one moves down-structure. The intensity of alteration along the faults and fractures also increases, especially within a few meters of the detachment fault itself.

About 100 m up the wash from the main road, a small road crosses the wash where the canyon forks. Take the left fork to the Picacho mine detachment fault (Figures 6, 7), where upper-plate Winterhaven Formation is juxtaposed against lower-plate Jurassic(?) gneiss. The detachment fault forms a distinctive ledge in the middle of the wash, reflecting the sunlight in the afternoon light. This microbreccia ledge exposure is light brown and forms the top of the lower plate. Shattered gneiss that looks almost like a conglomerate underlies the microbreccia ledge. Highly deformed Winterhaven and Jurassic(?) gneiss sit above the microbreccia, which has anomalous gold and arsenic values in other exposures to the north (Drobeck and others, 1986). The degree of alteration and deformation seen here is characteristic of the detachment exposures elsewhere in the Picacho basin, providing a guide to similar structures that are buried by the thin alluvial cover or postdetachment volcanic rocks. The combination of yellow and green along the detachment zone is a color alteration that is extremely characteristic of the detachment-fault exposures in this whole region.

Offset of the microbreccia ledge by small-scale normal and strike-slip faults mimics the more regional deformation of the Picacho area (Figures 6, 7). Postdetachment faulting has segmented the detachment complex, making it more difficult to define and trace from point to point. The clear join of the detachment fault exposed here with the Picacho mine low-angle faults is difficult to discern because of these postdetachment normal faults. One such major fault is exposed just upstream from the detachment fault (Figure 5), where the maroon volcanic rocks are downdropped against the detachment zone. From the top of the hill northwest of the detachment zone, this large normal fault can be traced across the foreground between the mine and the detachment fault. To the north, one can see the upper-plate rocks repeated along multiple normal faults that are truncated by the Picacho mine detachment fault.

This pattern of multiple normal faults that both feed into the detachment faults and cut them is typical of most of the areas of significant gold mineralization in the Picacho region. The complexity of the detachment-related deformation produced by these multiple generations of normal faults suggests that gold mineralization may be localized in the uppermost crustal levels of detachment systems, i.e., near their headwalls. Here the detachment faults would have been very near the surface and subjected to multiple periods of brittle overprinting by subsequent normal faults developed on progressively deeper detachment faults during continued extension. Such gold mineralization associated with shallow crustal levels probably forms one end of a continuum with the copper-iron mineralization that is so typical of many of the well developed and more coherent detachment systems, such as in the Buckskin and Whipple Mountains (Wilkins and Heidrick, 1982; Spencer and Welty, 1986; Lehman and others, 1987). These copper deposits seem to represent the mineralization along deeper levels of detachment systems and appear to lack economic quantities of gold.

Exploration for large-tonnage, low-grade gold deposits such as Picacho and Mesquite might thus be concentrated within exposures of the higher-level portions of regional detachment complexes, rather than near the detachment faults of some of the classical

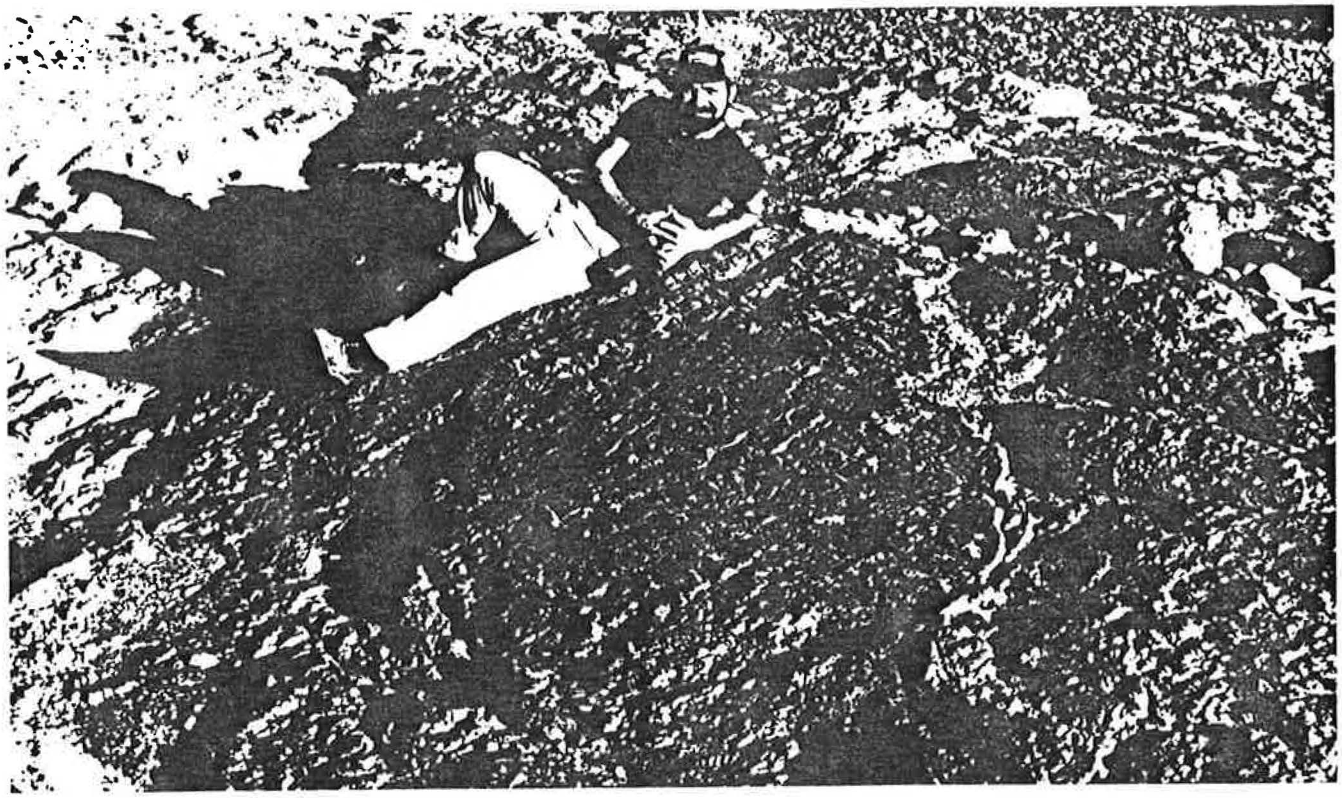


Figure 7. Picacho mine detachment fault with microbreccia ledge exposed about 250 m north of the Picacho mine. This is one of the uppermost of the multiple detachment faults exposed in the area and separates the Jurassic Winterhaven Formation from the underlying Jurassic(?) gneiss along this portion of its exposure. Up structure, this fault separates the Tertiary fanglomerate and volcanic units below the Quechan Volcanics from the lower-plate gneiss. Note the small-scale offset of the microbreccia by normal and strike-slip faults, which has effectively segmented this detachment fault and associated features into many individual slabs. The Picacho mine orebody has been similarly segmented from its original geometry of formation.

metamorphic core complexes. The spectacular fault exposures within the cores of many such detachment complexes are typically produced by the juxtaposition of middle-crustal rocks with upper-crustal rocks and do not represent the same structural or thermal regime that appears to have helped localize the gold mineralization at Picacho and Mesquite. Detachment faults in other ranges that have been called core complexes, such as the Black Mountains of Arizona, actually represent upper-crustal detachment faults that sit above deeper faults and would seem to represent attractive areas of exploration. Within individual complexes, such as the Whipple or the Chocolate Mountains, one side of the range is typically structurally higher than the other (SW side in both these ranges), making the higher structural level a more attractive target. In particular, exploration in the low-relief pediment regions around the margins of the upper-crustal portion of detachment complexes appears to hold the most promise for finding similar gold deposits.

Exploration for Mesquite- or Picacho-type orebodies should probably best begin with a geologic understanding of the diversity of detachment systems, the structural preparation produced by the multiple generations of faults, and the alteration and mineralization patterns that characterize such extensional fault complexes. Such an understanding can be most effectively gained by studying the Picacho and Mesquite regions within the context of the regional crustal extension and concomitant volcanism and plutonism that characterized this area in mid-Tertiary time. The overprint of this extension on the Mesozoic deformational and magmatic features has produced a geologically complex terrane, but one that offers the possibility for the discovery of other major gold deposits. Return to Phoenix.

ACKNOWLEDGMENTS

We would like to thank George Davis, Jon Spencer, and Will Carr for helpful reviews. We especially thank Evelyn VandenDolder for her review, which provided numerous insights that substantially improved the clarity and presentation of this field guide.

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Geology, Alteration and Mineralization of the Blackwater Hydrothermal Cell San Bernardino County, California

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Abstract

The Blackwater Prospect is characterized as a volcanic hosted precious-metal hydrothermal cell located within the California Desert Conservation Area.

The volcanic stratigraphy is comprised of rhyolite-rhyodacite pyroclastic lapillites, breccias, and tuffs, intercalated with volcaniclastic sediments. An intimate spatial distribution of flow-banded intrusive rhyolite with the pyroclastics suggests the prospect may represent a flow dome complex. Sedimentary structures suggest the intercalated strata may have been deposited as proximal epiclastic breccias and volcanic arenites.

Hydrothermal alteration is classified as acid-sulfate and composed of quartz-alunite-± kaolinite-sericite assemblages. Weak argillic alteration is generally pervasive. Moderate to intense zones of quartz-alunite ± kaolinite ± gypsum are structurally controlled. Zones of silicification range from weak to intense and are a function of: (1) structural control characterized as crackle breccias and stockworks and, (2) lithologic control related to primary porosity, i.e. the relative degree of welding, percentage of lithic clasts vs. matrix, and the clast size and degree of sorting.

Au, Ag and trace element mineralization is proportional to the intensity of fracture-filling silicification, i.e. stockwork and breccia, and matrix replacement silicification.

The Blackwater flow dome complex is characterized by; (1) acid-sulfate alteration assemblages, (2) brecciation and silicification, and (3) anomalous precious metal and trace element values which suggest this prospect represents the upper portion of a hydrothermal gold-silver system.

Location

The Blackwater Prospect is located approximately twenty miles east of the Randsburg-Johannesburg Mining District in San Bernardino County, in Sections 26, 27, 34, and 35, Township 29 South, Range 43 East. The prospect area is readily accessible by gravel roads east of U.S. Highway Route 395 (Fig. 1).

The prospect area occurs within the California Desert Conservation Area, is located west of the Blackwater Well Wilderness Study Area, north of the Historical Site at Blackwater Well, and south of the China Lake Weapons Testing Center.

History

No production or any record of activity was found in a literature search for the area. However, numerous prospect pits, shafts, adits, dumps and access roads reflect historic exploration activity. It is hypothesized, due to the proximity to the Randsburg-Johannesburg Mining District and Blackwater Well, the

prospects on the Butte were investigated for precious metals during the late 1800's and early 1900's. Later, in the 1950's-1960's, adits were driven to determine potential for uranium mineralization.

The Blackwater Well Historical Site, south of the Butte, was a watering station for the 20 mule teams which hauled borax from Death Valley to Mohave.

Westmont (formerly Nicor) staked the property in 1984 and conducted an initial evaluation. In 1987, the area was restaked by P. Drobeck, J.P. Rogowski and L.W. Watson, who leased the unpatented claims to Homestake Mining Company in 1988. A detailed evaluation has been conducted and a drilling program proposed to test this hypothesis.

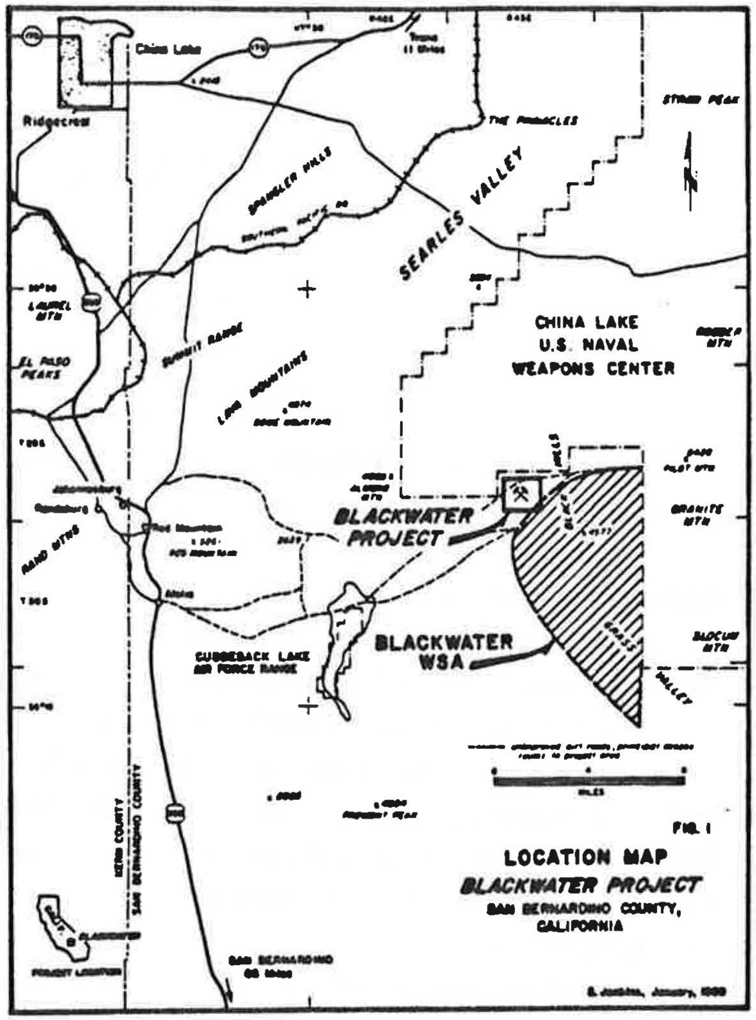

FIG. 1
LOCATION MAP
BLACKWATER PROJECT
SAN BERNARDINO COUNTY, CALIFORNIA

Regional Setting

The Blackwater Prospect is located in the north central part of the Mohave structural province which is bounded on the north by the Garlock Fault and on the south by the San Andreas Fault (Fig. 2).

The Pre-Tertiary strata consists of: (1) Pre-Cambrian to Paleozoic schists and gneiss of amphibolite grade and correlated to the Waterman Gneiss and Mesquite Schist (Jenkins, 1962), (2) Paleozoic metasediments of marine origin, predominately schists, phyllites, marbles and quartzites, (3) a Pre-Cenozoic (age uncertain) cataclastic mixture of granitic intrusives, metavolcanics, gneiss and schists, and (4) Mesozoic "granites" which probably represent the southern extension of the Sierra Nevada Batholith.

The Tertiary stratigraphy unconformably overlies Mesozoic granite and related metamorphic strata.

Regionally, middle-late Tertiary volcanics are dominated by flows, breccias, pyroclastics and volcaniclastic sediments of andesite to latite composition. Dikes, plugs, domes and necks which intrude the volcanics are spatially and genetically related. Volcanism appears to be localized along ENE-WSW and NW-SE fault/fracture trends and at intersections. These trends parallel the San Andreas and Garlock Faults. Proximal and distal late-Tertiary volcaniclastic sediments, alluvial lake deposits and fanglomerates are epiclastic derivatives of the

EXPLANATION

Qal	Quaternary deposits
Ms	Pleistocene-Miocene nonmarine sediments
Mv	Pleistocene-Miocene volcanics
Ti	Tertiary intrusives
+gr+	Mesozoic granitics
m, IPm, pЄ	Other Pre-Tertiary rocks
	Contacts
	Faults

MODIFIED FROM GEOLOGIC MAP OF CALIFORNIA-TRONA SHEET, O.P. JENKINS EDITION, 1962, SCALE 1:250,000

Fig.2

REGIONAL GEOLOGY
BLACKWATER PROJECT
SAN BERNARDINO COUNTY, CALIFORNIA

S. Jenkins, January, 1989

volcanic/pyroclastic deposits. An extensive area is covered by Quaternary alluvium and fan deposits. Rhyolite-dacite pyroclastics and flows occur at Blackwater Butte.

The Butte is composed of silicic pyroclastics and intrusives deposited on a peneplain surface of Mesozoic granite. To the east, Quaternary basalts unconformably overlie Mesozoic granite and form a north-northwest trending uplifted horst, comprising the Black Hills. To the west, andesitic flows, breccias and pyroclastics crop out and define Almond Mountain. To the southwest, a northwest-trending rib of intrusive (and in part extrusive) dikes and plugs crop out. These high-level rhyolite-dacite intrusives may be genetically related to the intrusives exposed at Blackwater Butte, but are mineralogically and texturally different.

It is hypothesized that the silicic pyroclastics and spatially associated intrusive rhyolites which form Blackwater Butte represent a flow dome complex outcropping and in part preserved in a graben bounded by the Blackwater Fault on the north and an unnamed parallel northwest trending fault to the south (see Fig. 2).

Prospect Geology

Stratigraphy

Stratigraphic units which comprise the Blackwater Butte are predominately air-fall rhyolite-rhyodacite pyroclastics, epigenetic volcaniclastic sediments and breccias. These units define an oval outcrop pattern, approximately 6,500 feet east-west and 4,000 feet north-south. The volcanics unconformably overlie Mesozoic granitics along the northern, eastern and southern boundary. An intrusive flow banded rhyolite forms the western and southern boundary (see Fig. 3).

Approximately 500 feet of stratigraphy is exposed, which includes a basal lapillite-tuff unit (± 150 feet thick), volcaniclastic unit (± 350 feet thick) and a breccia unit (± 100 feet thick).

The basal lapillite is composed of a heterogeneous mixture of intercalated air-fall lithic lapillites, lithic tuffs with minor interbeds of water lain and fluvial reworked tuffs and lithic breccias. Individual bedded units range in thickness from a few millimeters to massive units as much as 6 feet thick, locally exhibiting graded bedding. The units are composed of varying proportions of lithic clasts and pumice fragments in a tuffaceous matrix. Clasts range in size from fine ash to 6 inches in diameter. Locally, granitic clasts, up to 3 inches in diameter, are contained within intercalated lithic breccias near the unconformable contact. The lithic lapillite unit is characteristically a slope former which reflects poor to moderate welding and a ubiquitous tuffaceous matrix. Sedimentary structures, including cross-bedding, scour and fill features are found in the water lain lithic breccias and lithic tuffs.

The lithic lapillite grades upward into poorly sorted, lithic-dominated volcanic sediments ranging from thinly laminated lithic siltstones to massive breccias 20 feet thick, containing clasts up to 5 feet in diameter. Bedding is characteristic of this unit with locally developed sedimentary structures, including normal and reverse grading, cross-bedding and scour and fill features. The matrix is typically very fine- to medium-grained pumiceous ash or silt-size lithic particles. Air-fall lithic lapillites and lithic tuffs are locally interbedded within the volcanic sediments. This unit, due to its sedimentary character and indurated silica-cemented matrix, is

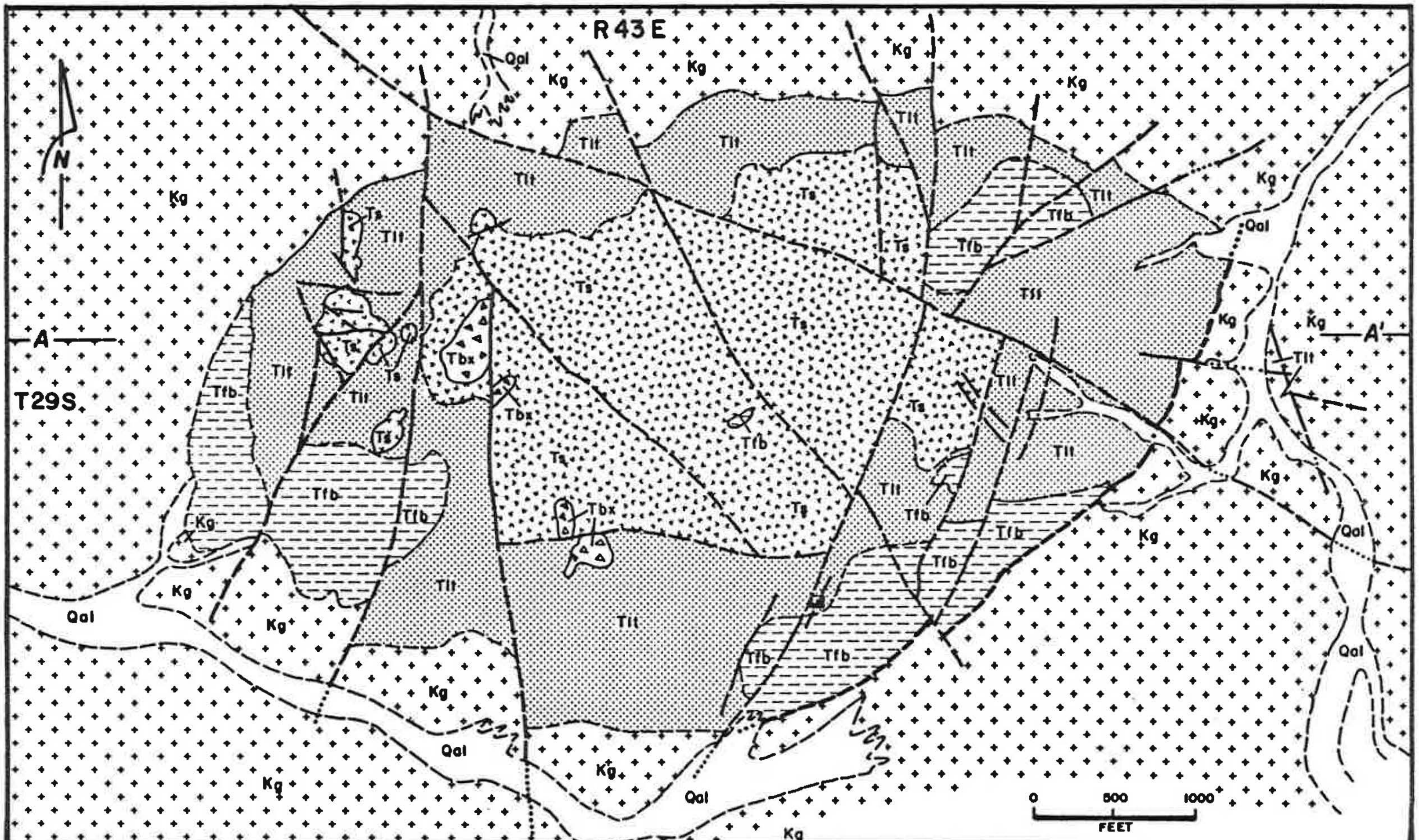

FIG. 3

QUATERNARY

Qal	Alluvium

UNCONFORMITY

MID-LATE TERTIARY

Tbx	Volcanic breccia
Tfb	Rhyolite
Ts	Volcanic sediments
Tlt	Lapillite and tuffs

CRETACEOUS

Kg	Biotite granite
	Contact
	Fault

GEOLOGY

BLACKWATER PROJECT

SAN BERNARDINO COUNTY, CALIFORNIA

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more resistent to erosion and forms subdued cliffs and steep outcrops relative to the underlying slope-forming ash-fall lapillite unit.

A volcanic breccia comprises the uppermost unit and is composed of a poorly-sorted chaotic mixture of all lithologic units and clasts from the flow banded rhyolite plugs. Distinct bedding is rare due to the coarse character of clast size which range from coarse sand up to 10 feet in diameter. The chaotic sorting, coarse size of the clasts, lack of bedding and diversity of clast composition (with a predominance of flow banded rhyolite) suggests this breccia unit may represent a proximal talus breccia or a proximal explosion breccia deposit. The breccia exhibits a conformable contact with the underlying volcaniclastic sediments.

The volcanic stratigraphy has been intruded by intricately flow banded rhyolite plugs and dikes. The plugs exhibit a crude concentric distribution cropping out along the western, southeastern and northeast sections of the Butte at or near the contact between the lithic lapillites and granite. Locally, small plugs and dikes crop out in the interior of the Butte. The flow-banded plugs exhibit well-developed concentric sheeted joints and flow banding parallel to adjacent contacts, which suggest a forceful emplacement of a viscous magma. The plugs may represent the surficial expression of a larger rhyolite intrusion at depth.

Alteration

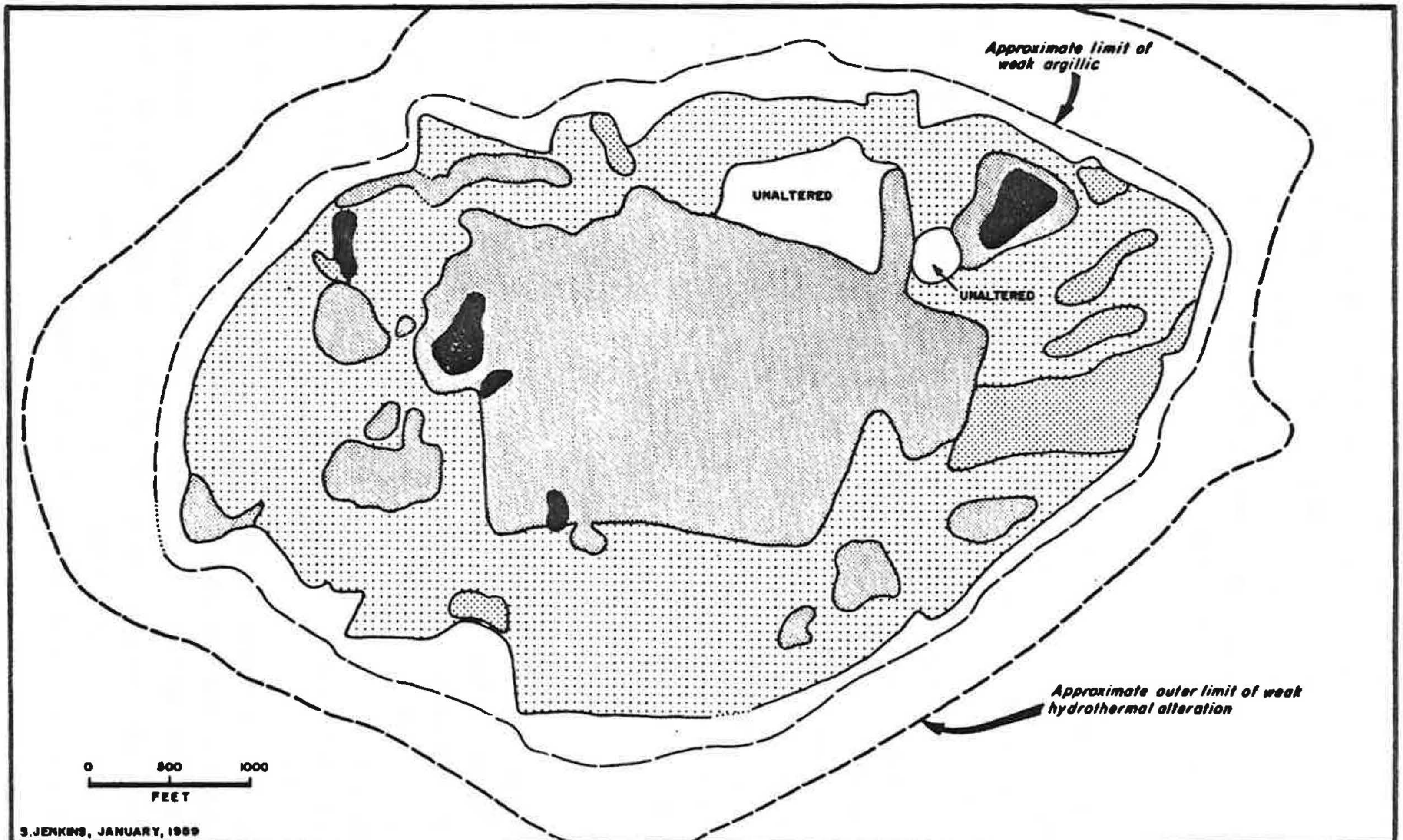
Hydrothermal alteration is characterized as acid-sulfate and composed of quartz-alunite ± kaolinite ± sericite assemblages, (Fig. 4).

The effects of argillic alteration are generally weak and pervasively developed over the Butte. Weak to moderate argillization is generally a function of primary porosity related to the proportions of matrix, clast content and degree of welding. Moderate to intense zones of quartz-alunite, kaolinite ± quartz and ± gypsum are structurally controlled along northwest, northeast and north-south trending conduits, and spatially confined to the fracture zones. The degree of lateral intensity, exhibited by leaching, is a function of primary porosity and structural preparation. Locally, in zones of intense leaching, only a residual spongy mass coexists with kaolinite and stockwork gypsum and relict textures of the original rock type have been obliterated.

Silicification is structurally controlled and confined to areas of stockwork and hydrothermal breccias, and pervasive matrix replacement of coarse volcanic breccias adjacent to hydrothermal conduits.

Stockworks and hydrothermal crackle breccias are best developed within and along the margins of the flow banded rhyolite plugs or in intensely fractured pyroclastics and volcaniclastics. These stockwork and breccia zones exhibit either elongation in northeast, north-south and northwest orientations. Hydrothermal breccias vary from weak to moderate to locally intense. Cryptocrystalline quartz is locally developed in and adjacent to fault zones and domains of intense stockworks. Disseminated pyrite, 1-3%, was observed only in zones of intense silicification.

Zones of weak to moderately intense silicification occur as a pervasive replacement of tuffaceous matrix in coarse lapillite and breccias adjacent to hydrothermal conduits. Locally, matrix and clasts are intensely silicified to the point at which primary textures are destroyed. Replacement silicification is predominately chalcedonic in character and parallels bedding planes defined by the coarse breccias units.



SILICIFICATION

INTENSE TO MODERATE

MODERATE TO WEAK

ARGILLIZATION

MODERATE TO INTENSE

WEAK

FIG. 4

ALTERATION

BLACKWATER PROJECT

SAN BERNARDINO COUNTY, CALIFORNIA

A weak argillic-propylitic halo is developed in the Mesozoic granite at the contact with the volcanics. Locally, quartz stockworks are developed in the granite adjacent to areas of intensely argillized volcanics. The intensity of argillization decreases from the contact and grades into propylitic and ultimately into unaltered granite within a few hundred feet. The argillic-propylitic halo strongly suggests the existence of a fossil hydrothermal system which has altered both the volcanic dome complex and adjacent Mesozoic granite.

The Butte exhibits varying proportions and intensity of goethite, jarosite and hematite which is a function of the supergene oxidation of hydrothermal pyrite.

Structure

The Blackwater Butte has been complexly faulted along northwest, northeast and north-south trends. Three principle structural domains have been recognized.

The western domain is dominated by north-south and northwest trending shear zones and normal faults. East-west and northeast-southwest trending faults and shears are less well developed in this domain. In general, bedding planes exhibit northerly and northwest strikes and dip moderately west and northwest. The western domain is terminated on the east by north-south and northwest normal faults.

The central domain is dominated by northwest-southeast and east-west trending normal faults. Northeast trending faults are subordinated. The lithic tuffs on the northern and southern flanks dip at moderate (25°-60°) angles toward the center of the butte. The overlying volcaniclastic sediments exhibit both northwest and northeast strikes and dip northerly at moderate angles (10°-40°) to the north. The boundary between the central and eastern domain is defined by a curvilinear north-northeast striking normal fault, with the east side down.

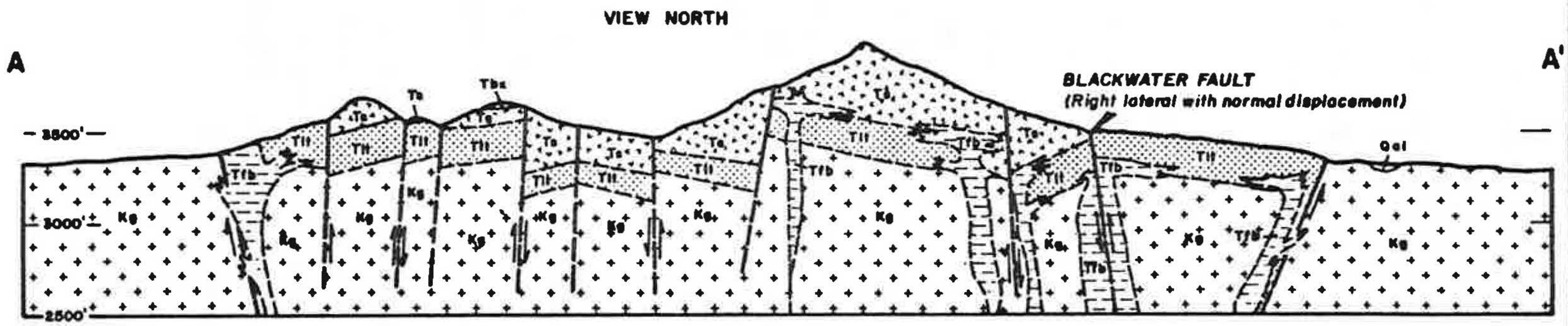
The east domain is dominated by northeast-southwest trending faults, northeast elongated rhyolite plugs, northeast-striking beds and joints which generally dip west and north. A northwest striking fault (parallel to the trace of the Blackwater Fault) truncates lithologies in the northeast corner of the Butte, with the northeast side down.

The Butte is complexly dissected in which a central core area has been uplifted relative to the flanks (see Fig. 5). Locally, coherent slide blocks mark the trace of normal dip slip faults and are gently tilted away and down slope from the upthrown side.

Rhyolite plugs exhibit a northeast elongation and generally occur along or near the contact between the granite and pyroclastic units. This distribution suggests the forceful emplacement of these plugs was guided along pre-existing faults and zones of weakness. Northeast and northwest joints and sheeted zones in the granite are the predominate sets.

Measured joints and bedding attitudes define two prominent structural trends in northwesterly and northeasterly directions. An east-west and north-south is less well developed.

Air photo lineations mimic these trends. In addition, these lineations, when viewed over the entire Butte and adjoining granite, exhibit a concentric pattern which defines an oval outline in the granite peripheral to the contact. Nested concentric patterns are observed within the Butte. These concentric patterns may suggest an intrusion at depth which is expressed at the surface as rhyolitic domes.



See Geologic Map for explanation (Fig.3)

FIG. 5

CROSS SECTION A—A'

BLACKWATER PROJECT

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Geochemistry

A surface and underground sampling program has been conducted in order to understand control of mineralization in relation to alteration and structure.

A total of 300 samples were taken during the evaluation, including 143 samples in a rock chip grid survey, 40 underground samples, and 117 select outcrop samples.

The anomalous rock chip samples are associated with silicification along structures, zones of quartz-alunite, hydrothermal quartz-stockworks, and replacement silicification. Approximately 90% of all samples exhibit anomalous values greater than the tabulated background values.

Summary of Geochemistry

	High Values	Background Values
Au	2.1 ppm	0.020 ppm
Ag	213 ppm	0.10 ppm
As	5500 ppm	50 ppm
Sb	1300 ppm	5 ppm
Hg	60 ppm	0.10 ppm

The anomalous precious metal values and trace element signatures indicate the existence of a precious metal hydrothermal system at Blackwater Butte and have aided in the identification of numerous target areas. Precious metals and trace element values and exposed alteration assemblages suggest high to moderate potential exists for concealed precious metal mineralization.

Conclusions

A detailed field evaluation of the Blackwater area has delineated a mineralized hydrothermal system. The identification of alteration assemblages (acid sulfate - quartz alunite), structural complexity, and anomalous geochemical signatures suggest there exists moderate to high potential for concealed precious metal mineralization.

A drilling program should be undertaken to test for precious metal mineralization which incorporates all available data. Specifically, the drill testing of targets should focus on zones of quartz-alunite and stockwork silicification, anomalous geochemistry, structural and lithologic intersections. Normally, preliminary ideas and hypotheses have to be refined during the evaluation and exploration of hydrothermal systems. This may include multiple drilling phases before a successful discovery is realized.

Acknowledgments

I would like to thank Homestake Mining Company for allowing this publication; Toni Hutcherson for the compilation of the text; Doris Weber for drafting the illustrations; review and comments from Bob Blakestad, Dick Kern, and Peter Drobeck.

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THE MOHAWK MINE: A BASE METAL-SILVER DEPOSIT RELATED TO POSSIBLE LATE CRETACEOUS NORMAL-SLIP MOVEMENT WITHIN THE CLARK MOUNTAIN THRUST COMPLEX, SAN BERNARDINO COUNTY, CALIFORNIA

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ABSTRACT

The Mohawk Mine lies within the Ivanpah Mining District, eastern San Bernardino County, California. Mineralization consists of a complex suite of carbonates, oxides and sulfides of zinc, lead, copper and silver. Previous researchers have suggested that the base metal mineralization occurs within a skarn zone developed at the contact between the Bonanza King Formation and Clark Mountain stock. Field mapping and laboratory petrographic studies have raised questions with this model. Specifically, the absence of a characteristic calc-silicate assemblage, hydrothermal alteration of the intrusive itself and close spatial relationship of ore bodies to fault zones are difficult to reconcile with a skarn model.

The mine is situated within a structural block bounded to the east by the Mesquite Pass thrust and the west by the Pachalka (Winters Pass) thrust. Three prominent north-northeast trending thrust faults have been mapped on the property. Two crosscut Cretaceous quartz monzonite indicating the most recent movement on the thrusts must be post-Jurassic. Reported ages for both the Mesquite Pass and Winters Pass thrusts are inconsistent (too old) with the observed relationships. Further, mineralization postdates both intrusion of the Clark Mountain stock and thrusting since the quartz monzonite has been altered adjacent to ore bodies, and some ore zones and their alteration halos parallel the plane of the thrusts.

Modification of a model proposed by Sharp (1984) for the Colosseum Mine explains the observed structural relationships. Pre-Cretaceous thrusting occurred along both the Winters Pass and Mesquite Pass thrusts. Thrusting was followed by intrusion of the Cretaceous Clark Mountain stock resulting in a 10-20° westward tilt of the existing strata. The tilt reactivated the thrust faults which experienced east to west gravity sliding (normal-slip), probably during late Cretaceous-early Tertiary. Delfonte volcanism (late Cretaceous) may have generated hydrothermal fluids which moved along the reactivated fault planes and emplaced the ore at favorable stratigraphic horizons within the host Bonanza King Formation.

INTRODUCTION

The Mohawk Mine is situated within the southwest portion of the Ivanpah mining district, 6 km west of the Molycorp Mountain Pass rare earth mine and 1.5 km north of Interstate 15 (Fig. 1). Mine workings on the south flank of Mohawk Hill are clearly visible from I-15. They are accessible from the Cima Road Exit by a series of secondary gravel and dirt roads, all of which are passable with 2-wheel drive vehicles.

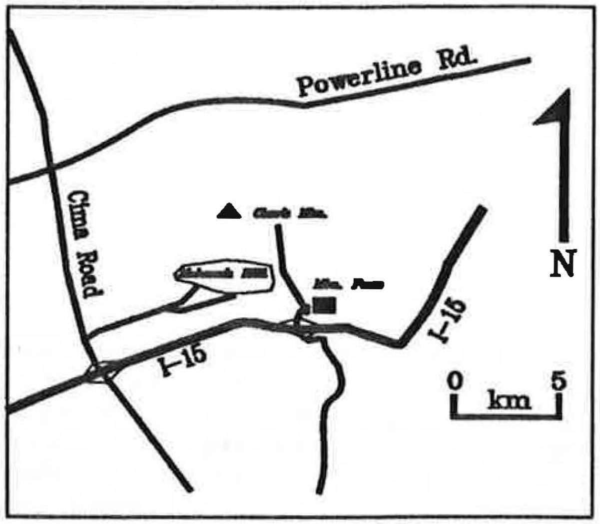

Fig. 1 Index map showing the location of Mohawk Hill. Mine workings are on the west end of the ridge.

HISTORY

The Mohawk Mine was worked briefly during World War I (1916- 1918). Three hundred tons of hand cobbed ore were shipped yielding 4 oz. of gold, 20,000 lbs. of copper and 250,000 lbs. of lead. The property was then idle until its acquisition in 1942 by the Ivanpah Copper Company. Production records are incomplete, but from 1942 to 1952 Ivanpah Copper reported the shipment of 16,700 tons of ore which produced 206 oz. of gold, 92,802 oz. of silver, 183,600 lbs. of copper, 2.9 million lbs. of lead and one million lbs. of zinc (Hewett, 1956).

Mapping of the existing underground workings which consist of seven adits, nine shafts and five prospect pits, suggests that additional unreported production may have occurred after 1952. The mine has been inactive since at least 1957 (Evans, 1958).

GENERAL GEOLOGY

Structure

The Mohawk Mine lies within the Clark Mountain thrust complex. This complex comprises the southernmost extension of the Cretaceous Sevier fold and thrust belt which trends southwest from Wyoming across Utah and southern Nevada into southeastern California. Within the belt there are three major thrust faults with a total minimum northeastward displacement of 65-80 km (Burchfiel and Davis, 1988). Only the Mesquite Pass thrust and Keaney-Mollusk Mine (KMM) thrust have previously been mapped in the area surrounding the mine (Burchfiel and Davis, 1971; Sharp, 1984).

The Mesquite Pass thrust is described as a moderately west dipping complex zone of anastomosing fractures which divides the thrust sheet into several major slices (Burchfiel and Davis, 1988). Intricate drag folding is common along the thrust plane. The general pattern

of thrusting in the central Clark Mountains (the vicinity of Mountain Pass) is to place Cambrian Bonanza King Formation above the Devonian Sultan Limestone. The latest movement on the Mesquite Pass thrust predates 190 to 200 m.y. (Burchfiel and Davis, 1973).

The KMM thrust (formerly Keystone thrust) lying 2 km east of the Mesquite Pass thrust is of markedly different character. It is described as a "classic" decollement by Burchfiel and Davis (1988) which has thrust Bonanza King Formation eastward over Cambrian Bright Angel Shale, Tapeats Sandstone and locally, Precambrian gneiss. The age of thrusting for various segments of this fault has been estimated at 138 m.y. (Sutter, 1968) to 84 m.y. (Sharp, 1984). Sharp (1984) suggests that the latest movement on the KMM thrust was actually dip-slip gliding of the upper plate from east to west.

During recent field sampling, outcrops of Precambrian (?) gneiss and schist were discovered 4 km west of the Mohawk Mine. The rocks lie in an area of low hills surrounded by extensive alluvial cover, but field relationships suggest the crystalline metamorphics lie above and to the west of Wood Canyon Formation (?) quartzites. A north-northeast trending thrust fault provides the best explanation for the observed structural relationship. This thrust represents the southern extension of the Pachalka thrust mapped 6 km to the north by Burchfiel and Davis (1988). The Pachalka thrust is correlative to the Winters Pass thrust, the third major thrust fault within the Clark Mountain thrust complex. The age of the Winters Pass thrust is not firmly established. Field relationships suggest it is older than the Mesquite Pass thrust (Burchfiel and Davis, 1973), but recent mapping of the Pachalka thrust indicates it may be as young as Cretaceous (Burchfiel and Davis, 1988).

The structural picture has been complicated by mid-late Tertiary extensional detachment faulting and recent Basin and Range normal faulting. Hewett (1956) mapped two major normal faults in the central Clark Mountains, the Clark Mountain fault and the Ivanpah fault. The former is now recognized as the KMM thrust, while the latter is probably a true manifestation of recent Basin and Range tectonics. Sharp (1984) also maps a low angle, Basin and Range, normal fault near the Colosseum mine, north of Mountain Pass and Evans (1958) maps several normal faults of uncertain origin in the Mescal Range.

A small scale detachment fault has recently been recognized in the northern Clark Mountains; no similar features have yet been mapped in the central Clark Mountains (Burchfiel and Davis, 1988). In addition, a major detachment fault has been mapped in the Kingston range to the north (Burchfiel, et al., 1984).

Stratigraphy

Within the Clark Mountains a more or less complete Paleozoic-Mesozoic Cordilleran cratonal section is preserved ranging from basal Cambrian through Jurassic. This sedimentary package has been unconformably deposited on a series of Precambrian crystalline rocks. Jurassic-Cretaceous stocks intrude the sedimentary rocks and Tertiary volcanics overlie the older units.

In the central Clark Mountains the basement consists of Precambrian paragneiss and schist (Dobbs, 1961). Regional foliation in the gneiss strikes northwest (McClure, 1988). Locally, the gneisses have been intruded by Precambrian age alaskite and pegmatite dikes, and at Mountain Pass by an alkali syenite complex.

Paleozoic sedimentary rocks in the central Clark Mountains range in age from Cambrian to Pennsylvanian (Dobbs, 1961). East of the Mesquite Pass thrust Cambrian Tapeats Quartzite rests unconformably on Precambrian basement. The Tapeats is in turn overlain by Cambrian Bright Angel Shale, Cambrian Bonanza King, Devonian Sultan Limestone, Mississippian Monte Cristo Limestone and Pennsylvanian Bird Spring Formation. The Bonanza King lies in fault contact with the underlying units and is thought to represent the sole of the major KMM thrust sheet (Burchfiel and Davis, 1981). West of the Mesquite Pass thrust the Precambrian-Cambrian sequence (the Precambrian Sterling Quartzite, Cambrian Wood Canyon Formation, Cambrian Zabriskie Quartzite and Cambrian Carrara Formation) lie comformably beneath the Bonanza King.

The Teutonia batholith, a composite intrusive consisting of seven stocks, ranges in composition from granite to quartz monzonite and in age from Jurassic to Cretaceous (Beckerman, et al., 1982). In the central Clark Mountains the Clark Mountain stock is predominantly quartz monzonite. Although the age of the Clark Mountain stock has not been firmly established, Hewett (1956) suggests Cretaceous. The Delfonte volcanics of late Cretaceous age represent the final phase of batholithic intrusion. Much of the Delfonte volcanic sequence has been removed by erosion, but Burchfiel and Davis (1971) believe the composite Mesozoic volcanic/plutonic sequence represents the remnants of an arc terrane.

Cenozoic volcanics are common throughout the eastern Mojave. The Cima volcanic field lies 12 km to the southwest of the Clark Mountains. Tertiary volcanics are generally felsic, ranging in composition from rhyolite to dacite, while Recent volcanism is much more variable with basalts dominant (Wilshire, 1988). Associated Tertiary and Quaternary sediments are largely volcaniclastic. In the central Clark Mountains Cenozoic volcanics are generally absent.

MOHAWK MINE

Stratigraphy

All mine workings on Mohawk Hill lie within the Bonanza King Formation (Fig. 2). The Mesquite Pass thrust which forms the contact between the upper plate Cambrian Bonanza King and lower plate Devonian Sultan Formation lies 2 km east of the property. A small pod of Zabriskie (?) Quartzite has been mapped in fault contact with the Bonanza King near the west boundary of the mine property.

The Bonanza King consists essentially of two units; alternating thin bedded blue-gray and tan-white limestone (Fig. 3), and dark gray shaley dolomite. In thin section the limestone is finely-crystalline with minor epidote and idocrase(?), the latter pseudomorphed by iron oxides. The presence of epidote and idocrase suggest weak contact metamorphism. A sharp fault contact separates the limestone from the overlying shaley dolomite. This unit is characterized by a thin, basal, shaley dolomite grading upward into a finely-crystalline,

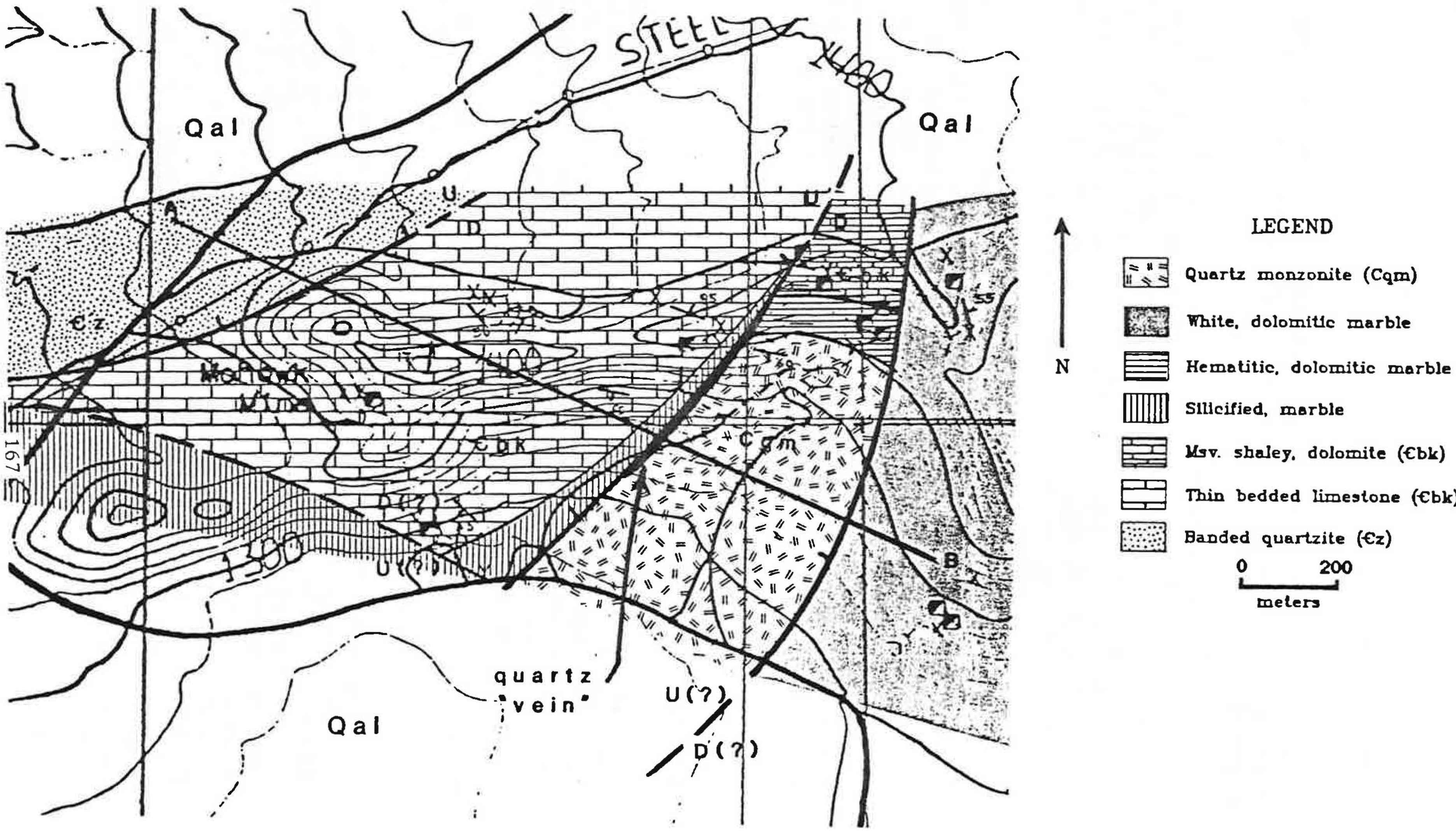

Fig. 2 Plan map of the Mohawk Mine property.

massive gray dolomite (Fig. 4). The shaley dolomite is thought to be the marker horizon separating the lower Papoose Lake Member of the Bonanza King from the upper Banded Mountain Member.

A small outcrop of the Clark Mountain stock occurs along the south flank of Mohawk Hill. Its contact with the Bonanza King strikes east-west and dips 30° to the south. The intrusive is truncated both to the northwest and southeast by faults. Drilling indicates the intrusive is sill-like, averaging 40 meters in thickness (Wiebelt, 1949). The rock has been mapped by Hewett (1956) as a quartz monzonite, and Evans (1958) indicates that in thin section it consists of 30% quartz, 20% plagioclase, 40% k-spar and 5% biotite. Samples of the intrusive taken adjacent to the contact with the Bonanza King locally contain minor secondary quartz and sulfides as fracture fillings.

A massive quartz "vein" was reported by Hewett (1956) at the intrusive-Bonanza King contact. The "vein" is clearly visible as a ridge of bull quartz a few meters thick trending northeast across the south flank of Mohawk Hill (Figs. 5,6). Hewett stated that this was one of several veins, however, surface mapping indicates only a single vein following the plane of a northeast trending fault. Although the quartz vein is unmineralized at the surface, in underground workings it is locally veined and replaced by later ore mineralization. Joseph (1984) suggests that the quartz "vein" of Hewett is a zone of silicification formed during intrusion of the Clark Mountain stock. In this interpretation the "vein" is an alteration halo adjacent to the stock.

Structure

The Bonanza King Formation strikes generally northwest and dips 20-30° to the southwest (Hewett, 1956 and Evans, 1958). However, along the crest of Mohawk Hill extreme local variation in both dip angle and direction were noted. The intricate nature of folding on outcrop (See Fig. 3) is reminiscent of the large scale decollement folds characteristic of Alpine-type regional thrusting and may indicate a much greater degree of local structural complexity than reconnaissance scale mapping can hope to decipher.

Four faults have been mapped on the mine property. Three trend roughly northeast, the strike becoming more northerly from west to east. The fourth fault has tentatively been assigned a west-northwest strike.

The westernmost of the three northeast striking faults was previously mapped by Dobbs (1961)(Fig. 7). He suggests the fault is a low angle west to east thrust with Tapeats Quartzite (Zabriskie ?) above Bonanza King. Two additional northeast trending faults were recognized during recent field mapping. The westernmost of these has thrust basal Papoose Lake (?) limestones over Banded Mountain (?) dolomites and locally, quartz monzonite. The portion of the fault zone which juxtaposes Bonanza King and intrusive is marked by the prominent quartz ridge discussed above. The eastern fault has a nearly north-south strike and steep dip to the west. While the fault trace is easily recognizable its sense of motion is more difficult to establish. The block to the east of the fault consists of coarsely-crystalline, white dolomitic marble of uncertain origin. We are interpreting this fault as a thrust similar to those mapped to the west, but acknowledge the possibility that it may be related to more recent Basin and Range tectonics.

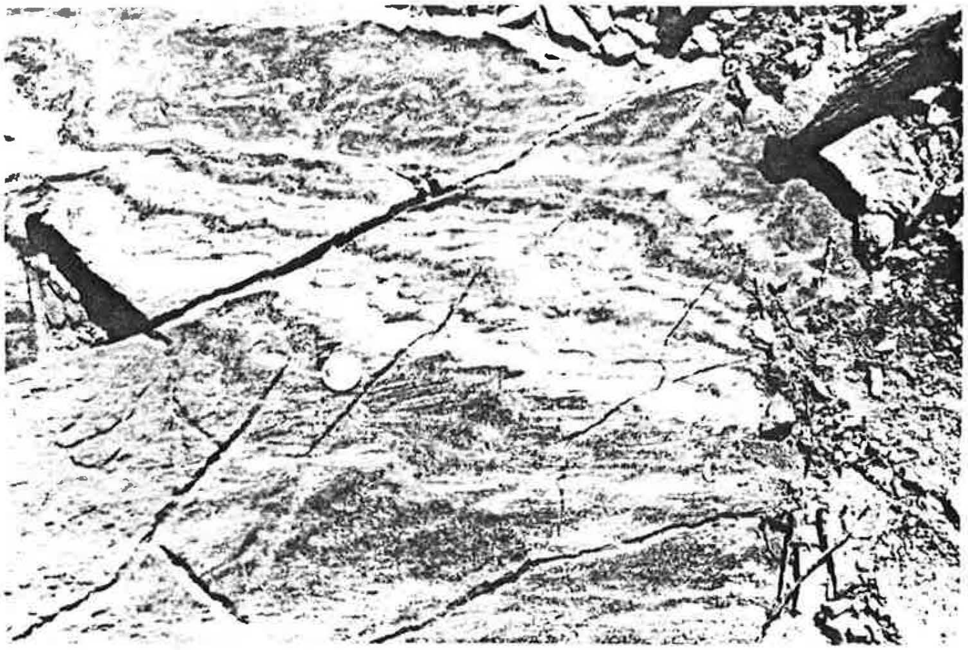

Fig. 3 Thin bedded blue-gray and tan-white limestone of the lower Bonanza King Formation.

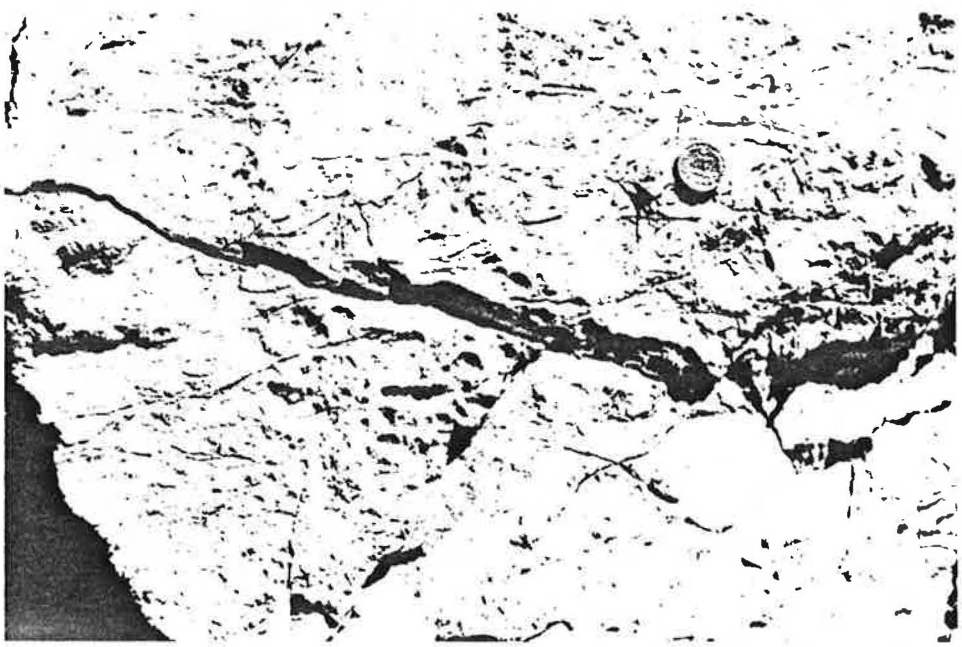

Fig. 4 Outcrop of massive gray dolomite, upper Bonanza King Formation.

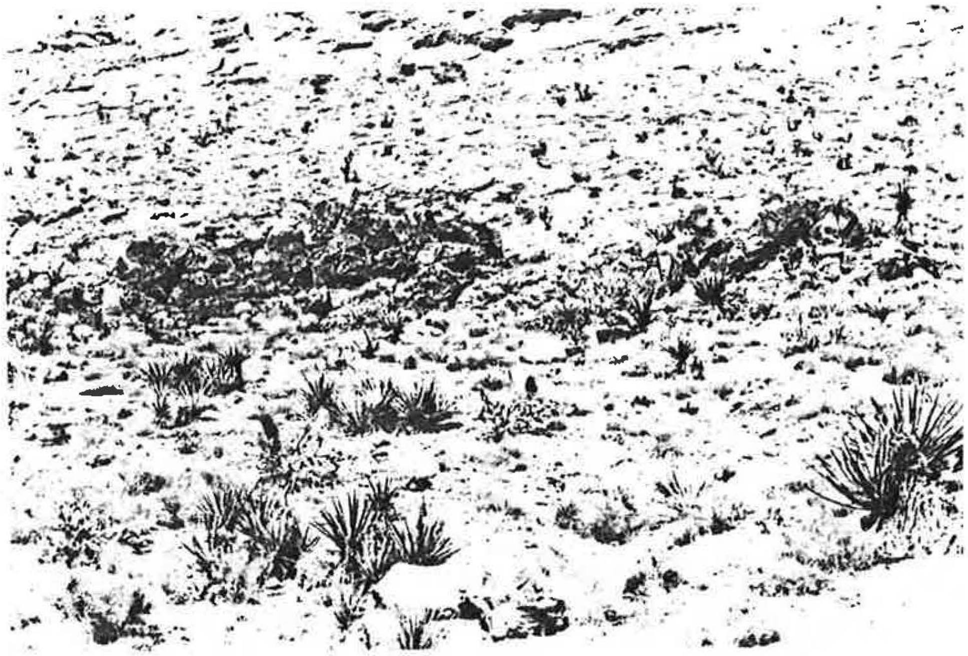

Fig. 5 Quartz vein (dark material, center of photo) outcropping on the south flank of Mohawk Hill.

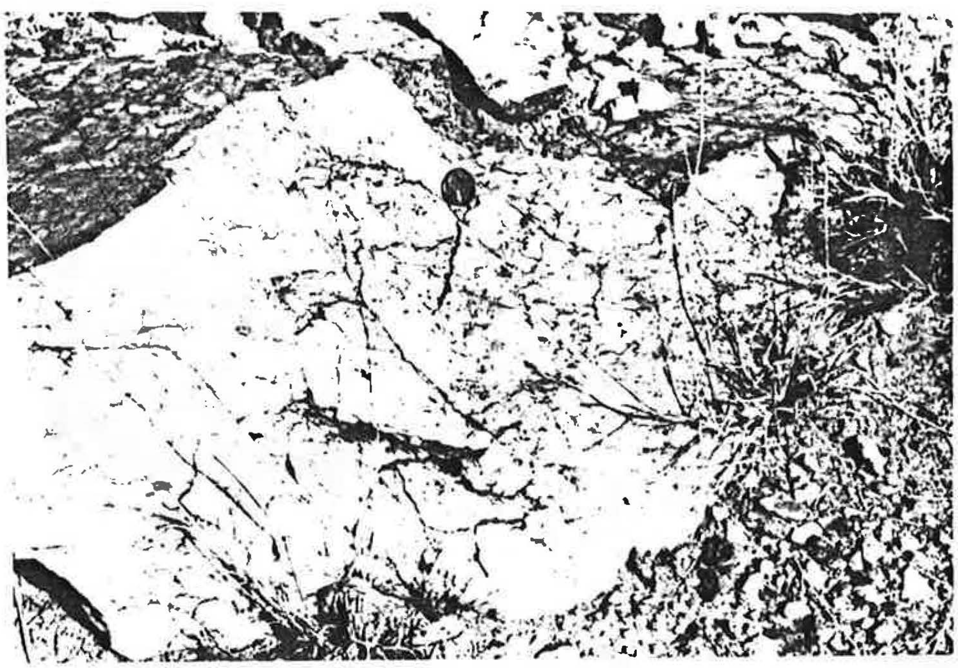

Fig. 6 Closeup of quartz vein shown in Figure 5.

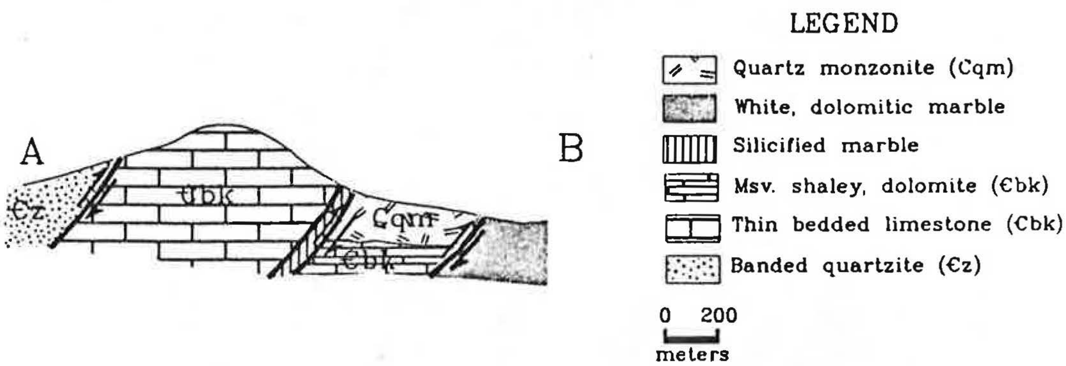

Fig. 7 Generalized cross section from A to B (Figure 2). Not to scale vertically.

A fourth fault has been mapped near the west end of Mohawk Hill trending west-northwest. It has no surface expression, but its presence is suggested by dolomitic marble juxtaposed against unaltered Bonanza King. The fault is tentatively depicted as dip-slip with the southwest side up.

Ore Mineralogy

The ore mineralogy of the Mohawk Mine is complex and variable. Cerrusite is dominant, but smithsonite is common as are the copper carbonates malachite and azurite. Minor chrysocolla was noted on dumps. Galena and sphalerite were reported by Hewett (1956), native silver and gold by Evans (1958) and chalcopyrite by Joseph (1984). Gangue consists of abundant iron and manganese oxides in a matrix of coarsely-crystalline quartz and calcite (Fig. 8). Minor jarosite and plumbojarosite and pyrite were also noted. Assays for silver from composite dump samples averaged 9 oz./ton. The silver bearing species is uncertain, but there seems to be an association with patches of fine-grained black material (probably cerrusite), samples of this material assaying in excess of 100 oz./ton.

Alteration

Hypogene alteration consists of intense silicification, widespread recrystallization of the Bonanza King Formation and local sericitic and argillic alteration of quartz monzonite. Weathering has produced a prominent secondary gossan of iron oxides overlying the ore zone.

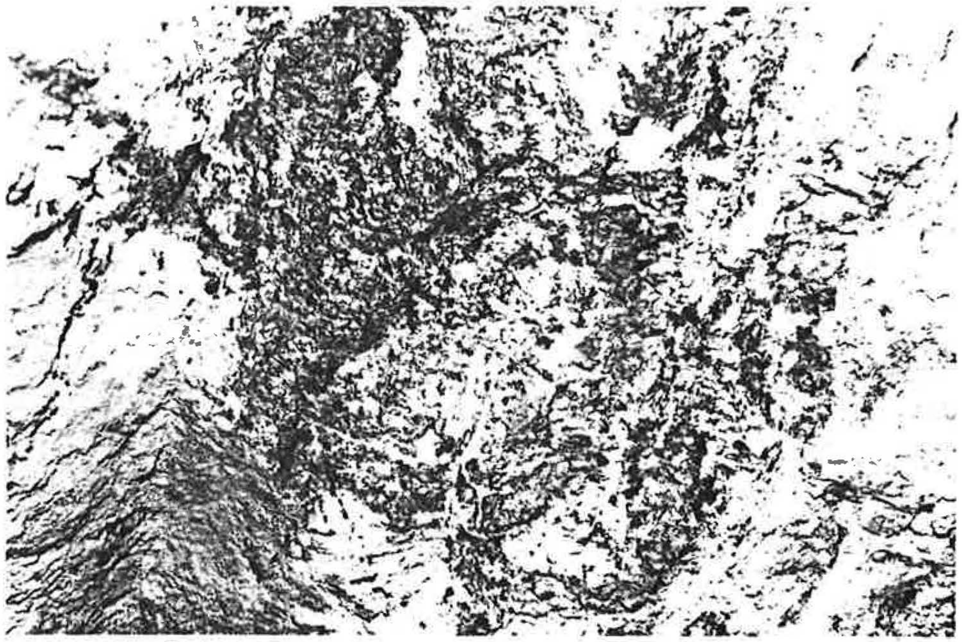

Fig. 8 Mineralization in underground workings. Black material (left center) is a mixture of sulfides, lighter gray (lower left) is iron oxide and very light gray to white predominantly quartz. Scale from right to left side of the photo approximately one meter.

Intense silicification is restricted to a zone less than 10 meters wide immediately adjacent to the intrusive (Fig. 9). The alteration is best seen in surface outcrop as a massive "vein" of fine-grained quartz on the south flank of Mohawk Hill. Locally, ore mineralization occurs as fracture fillings and disseminations within the silicification, but it is generally of low grade. Replacement by the fine-grained silica has been so pervasive as to obliterate the original carbonate host.

Ore mineralization lies within a zone of moderate silicification and recrystallized limestone and dolomite of variable thickness (2-10 meters) adjacent to the massive quartz. Previous workers (Joseph, 1984) have characterized this zone as a tactite or skarn adjacent to the intrusive. Examination of surface and underground exposures fails to confirm the presence of the typical calc-silicate suite associated with skarn formation. The only indication of calc-silicate alteration is a small exotic block of talc-tremolite schist on the north side of Mohawk Hill and scattered grains of epidote and idocrase in largely unaltered Bonanza King Formation several hundred meters from the intrusive contact. Recrystallization of the Bonanza King host has generally resulted in a coarsely-crystalline, mottled dolomite, herein termed marble in deference to previous workers.

Quartz monzonite adjacent to ore zones has been subjected to moderate to strong sericitic alteration and weak argillic alteration. Biotite has altered to a mixture of iron oxides.

A 100 meter thick cap of limonite/hematite alteration overlies the ore zone. The altered zone can be clearly seen as the dark brown horizon dipping moderately (20-30°) to the west as one drives north toward the mine workings. In hand sample the alteration consists of disseminated grains of iron oxides and iron oxide rims around sulfides. While the iron oxides

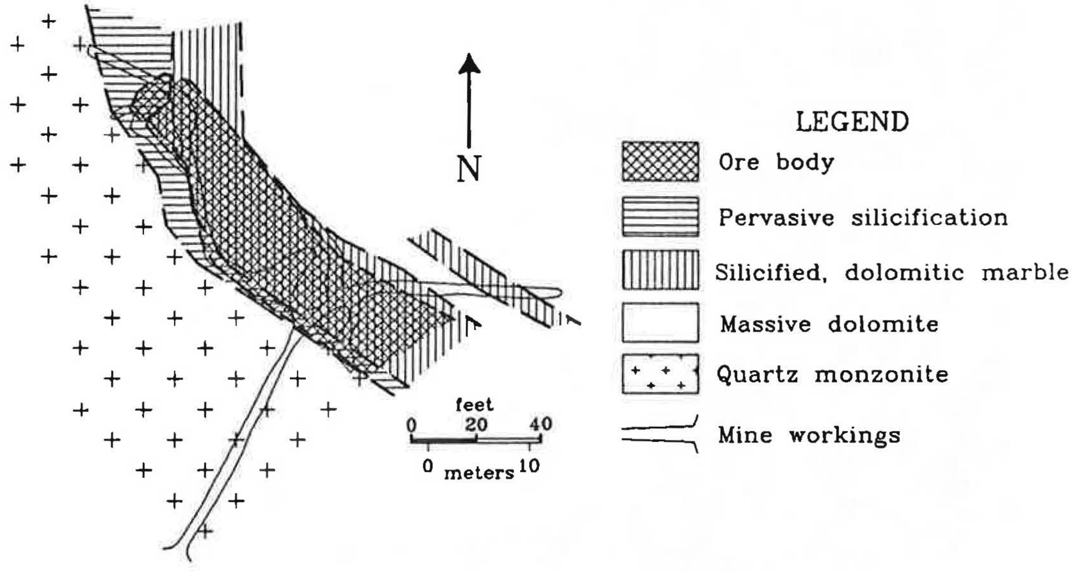

Fig. 9 Underground mine map showing the relationship of alteration to ore mineralization.

are dominant, manganese oxides and minor carbonates are also present. Samples from this zone generally contain less than 1 oz./ton silver. Exceptions are samples from small (less than one meter thick) high-grade, veins crosscutting the alteration zone.

Ore Controls

Several small ore bodies have been mined on the property. In many cases existing workings are no longer accessible. The largest ore body lies along the contact between the Bonanza King Formation and quartz monzonite intrusive. It strikes northwest parallel to the contact and perpendicular to strike of the thrust faults. A second smaller ore body lies to the west and appears to strike parallel to the adjacent thrust fault. The early Mohawk workings on the west end of the ridge exploited a third small ore body possibly related to the westernmost thrust. In addition, numerous vertical fractures above the main ore zones are mineralized (Fig. 10).

DISCUSSION

The only paper which has discussed genesis of the Mohawk mineralization (Joseph, 1984) suggests the deposit is a skarn developed at the contact between the Teutonia quartz monzonite and Bonanza King Formation. Joseph acknowledges that skarns are characterized by an assemblage of Ca-Mg-Fe-Al silicates, but states that such alteration is lacking within the skarn ore zones of the Ivanpah district, and, furthermore, that evidence of structural

Fig. 10 Mineralized vertical fracture (left center of photo) in altered Bonanza King Formation. Vein approximately 0.35 meters thick.

control of mineralization is often present. Other characteristics of Mohawk mineralization listed by Joseph are common to any ore deposit of hydrothermal origin. We accept the skarn model as a possibility, but favor an alternative model more consistent with the lack of skarnification and the observed structural relationships on the property.

We can place some time constraints on the model based on the observed geologic relationships. Latest movement on the thrust faults postdates intrusion of the Clark Mountain stock since quartz monzonite forms the hanging wall and footwall of separate thrusts. Furthermore, mineralization must postdate both thrust faulting and intrusion since traces of the fault are obliterated in strongly mineralized mine workings, some ore zones and alteration halos parallel fault strike, and sericitic and argillic alteration occur in footwall quartz monzonite of the central fault. The Mesquite Pass thrust to the east of the mine is Jurassic. Burchfiel and Davis (1988) suggest the Winters Pass-Pachalka thrust to the west is even older. If the thrust faults at the mine site are related to one of the aforementioned major thrusts, as seems likely, we must accept a Jurassic or older age for the faults. The age of the Teutonia batholith has not been firmly established near the Mohawk mine, but Beckerman et al. (1982) and Hewett (1956) favor Cretaceous for this portion of the batholith. This presents a dilemma since the Mohawk thrusts clearly cut the Cretaceous intrusive. Even if we suggest the Mohawk faults are correlative to the Pachalka thrust and of possible Cretaceous age (Burchfiel and Davis, 1988) we still are left with the problem of reconciling the circulation of hydrothermal fluids in a compressional tectonic setting.

Sharp (1984) discussing the structural evolution of a gold mineralized breccia pipe 9 km to the northeast of the Mohawk provides a model which might have some application. He proposes a period of early thrust faulting prior to 190 m.y. for the Winters Pass and Mesquite Pass thrusts and 130 m.y. for the KMM thrust. Intrusion of felsitic magmas lasting until about 90 m.y. ago tilted the Clark Mountains 10-20° to the west. This initiated an east to west gravity slide along the KMM thrust during early Tertiary or late Cretaceous (60-90 m.y.).

Since the Mohawk mine lies to the west of the KMM and Mesquite Pass thrusts a slightly modified sequence of events may be suggested. The Mohawk faults may represent branches of the Mesquite Pass thrust or more likely a series of shears comprising the Winters Pass thrust. Thrusting along these faults culminated at least 190 m.y. ago. Westward tilting of the Clark Mountains from 130 to 90 m.y. ago in response to intrusion of the Clark Mountain stock would initiate east to west gravity sliding along the reactivated faults explaining the offset of the younger quartz monzonite sill. The episode of gravity sliding coincides well with extrusion of the Delfonte volcanics at 87-85 m.y., the latter possibly providing the hydrothermal fluids responsible for Mohawk mineralization.

In summary, our model proposes that Mohawk mineralization represents mesothermal "vein-type" mineralization emplaced in response to early Tertiary-late Cretaceous volcanism. Further the mineralization was channeled through and deposited in reactivated Mesozoic thrusts, the reactivation occurring in response to gravity sliding induced by westward tilting of the Clark Mountains.

Acknowledgments

The authors wish to express their appreciation to Mr. William Hubbard, present owner of the Mohawk Mine. He provided access to the property for the purpose of mapping and sampling as well as unpublished assay and geological reports. A special thanks also goes to the Geological Sciences Department at Cal Poly for providing partial funding as well as time to complete field mapping.

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THE CASTLE MOUNTAIN GOLD DEPOSIT, HART DISTRICT
SAN BERNARDINO COUNTY, CALIFORNIA

Harold Linder
Consulting Geologist
Tempe, Arizona

I. Location and Access

The Castle Mountain gold deposit is located 60 miles south of Las Vegas and 15 miles southwest of Searchlight, Nevada in the old Hart Mining District (Fig. 1). Mineralization occurs at the southern end of the range at an elevation of 4500 feet in terrain typical of the Eastern Mohave Desert.

Current access is 51 miles from Las Vegas on Interstate 15 to the Nipton exit and then 29 miles on surfaced and dirt roads past Ivanpah and Barnwell to the site. Future preferred access will be 18 miles southwest from Searchlight along an old railroad grade.

Fig. 1 Location Map

The Original Discoverers of Hart, Cal.

James Hart — Clark Hitt — Bert Hitt

Fig. 2 The Original Discoverers of Hart, California (Courtesy Casebier, 1987)

Another View of Hart

Fig. 3 Early View of Hart, California (Courtesy Casebier, 1987)

II. History

The Hart Mining District was discovered in December 1907 by James H. Hart and the brothers Bert and Clark Hitt (Ely, 1987). Word spread quickly and two months later the newly formed town of Hart had a population of 700 and a mining magazine of the time reported that "gunplay and litigation have broken out." At its peak, Hart had 400 tent and frame buildings, 6 saloons and a newspaper, but no churches or schools (Figs. 2 and 3).

The original discovery was on a vein which carried 11 ounces of gold per ton, worth about $5,000 per ton at the current price of gold. Later, a vein was found which carried 500 ounces per ton. The veins and stringers carrying these very high values were very narrow, with widths of only a few inches, and most of the ore mined averaged one to two ounces per ton. The boom was short-lived as the coarse, high grade gold in veins proved to be very limited in extent and did not continue to depth. In 1910, only three years after the first discovery, the town had a population of only 40.

In the early 1920's mining development began on the large clay deposits located immediately west of the gold deposits. In the 1930's large quantities of clay were shipped from the P.S. Hart mine, which now is a large, prominent open pit with one wall over 200 feet high. Most of the clay was used for "sanitary ware" (i.e., toilets and lavatories) but more recently it has been used in the popular Franciscan Ware and in floor and wall tile. Another clay deposit, the C-1 Clay Mine, is marked by an open pit which now occupies much of the original townsite of Hart. Annual clay production today is estimated at about 10,000 tons, depending upon market demand.

Efforts were made during World War I to reopen the gold mines at Hart but they were unsuccessful. In 1933-42, the Big Chief mine was operated as the Valley View by underground mining and a cyanide mill. However, only minor gold production resulted.

VICEROY GOLD CORPORATION CASTLE MOUNTAIN PROJECT			
DEPOSIT	TONS ORE	oz./ Au / ton	oz./ Au
Mineable Reserves			
Jumbo South	8,832,000	.051	450,432
Lesley Ann	10,328,000	.065	671,320
Oro Belle	6,780,000	.044	298,320
Total	25,940,000	.055	1,420,072
Geological Reserves			
South Extension	7,108,900	.034	241,703
Jumbo	2,986,600	.066	197,116
Hart	3,376,000	.055	185,680
Total	13,471,500	.046	624,499

Table 1 Ore Reserves at the Castle Mountain Project (Viceroy Resources Corporation 1988 Annual Report)

III. Current Developments

Viceroy Gold Corporation has announced combined mineable and geological reserves of 40 million tons in 6 deposits with a total of 2 million ounces of gold in the ground (Table 1). Viceroy has applied for the major permits required and an Environmental Impact Statement has been submitted to the Bureau of Land Management as part of a Plan of Operations. Approval is expected in mid-1989 and construction will begin immediately upon approval by the BLM. Open pit, heap leach production of gold should commence about six months after construction begins.

Mr. D. Ross Fitzpatrick, President of Viceroy, became involved in the area in December 1983 on the recommendation of Mr. Ed Holt, Consulting Geological Engineer, and acquired a 41% interest in 24 claims covering the Oro Belle deposit, then being explored by Vanderbilt Gold Corporation. The writer examined the area as Consulting Geologist to Viceroy in June 1985, recognized the district potential, and recommended a major

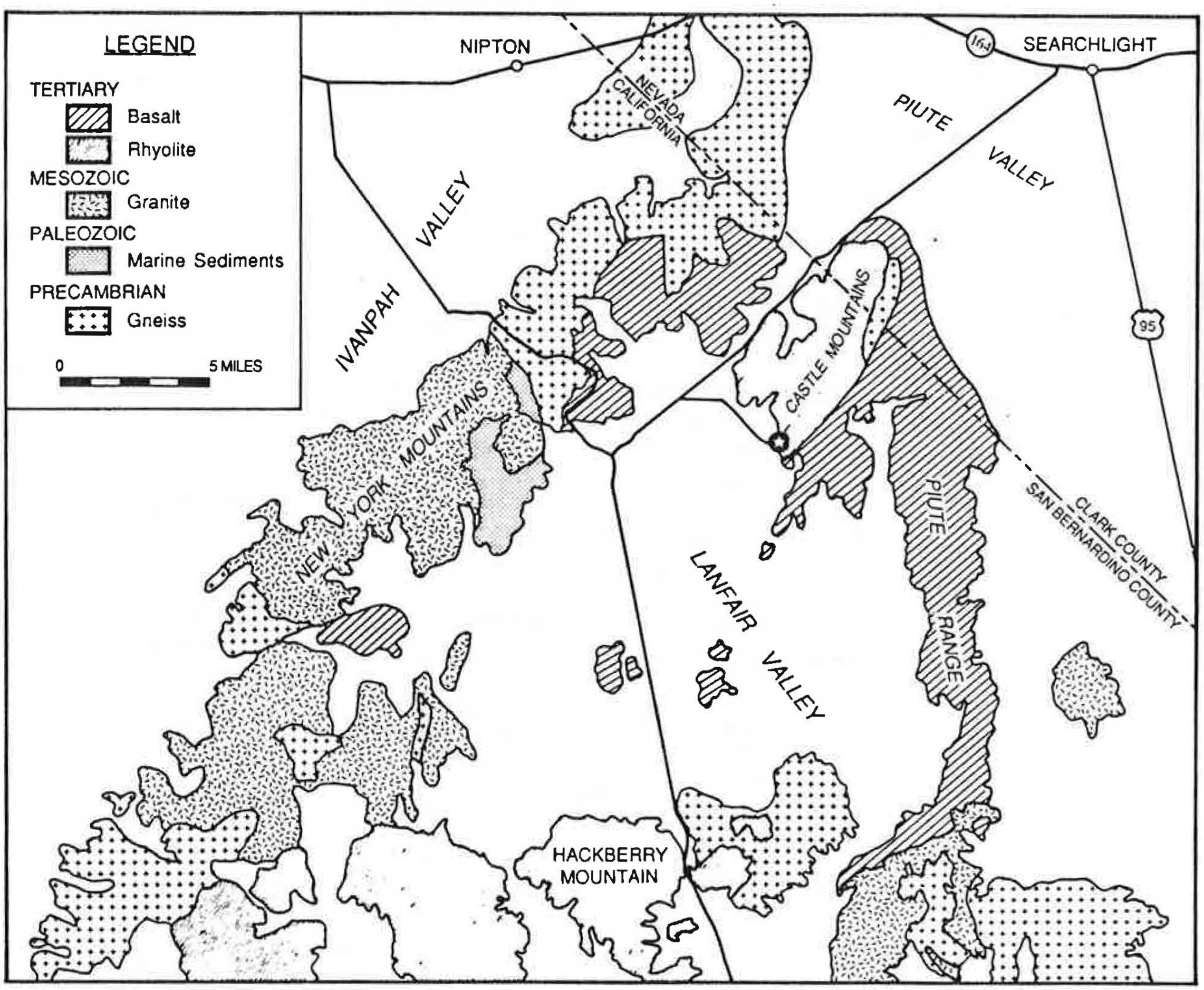

Fig. 4 Regional Geology

exploration program. I began field direction of exploration for Viceroy in September 1985 and discovered the Jumbo South deposit in February 1986 and the Lesley Ann deposit in September 1986.

The Jumbo South deposit is located under and adjacent to an old, minor gold occurrence that is similar to hundreds, and perhaps thousands, of other gold occurrences in the California Mohave Desert. The Lesley Ann deposit is completely buried by 300 feet of gravel and was discovered by good geology and good luck. Many similar deposits probably occur in the Mohave Desert with absolutely no surface indication of gold.

Viceroy has greatly expanded its property position by claim staking and negotiations and now owns 100% interest in more than 2,000 claims (65 square miles). Expenditures to date exceed $15 million for property acquisition, drilling (343,000 feet in 634 holes), geological mapping, geochemical surveys, metallurgical tests and reclamation studies. Additional capital costs to place the property into production are estimated at $35 million.

IV. Geologic Setting

A. Regional Geology

The Castle Mountains form a small range at the northern end of the Lanfair Valley in California and extend north into Nevada (Fig. 4). The general area is composed of Precambrian gneissic basement and local Paleozoic marine sediments intruded by Cretaceous Teutonia quartz monzonite and overlain by Miocene rhyolites, andesites and basalts.

The Castle Mountain range (Fig.5) is underlain by a Proterozoic basement composed chiefly of gneiss with lesser amounts of schist and alaskite. This is overlain by Miocene andesitic flows and sediments and by rhyolite flows, domes and pyroclastic rocks which trend north-northeast and dip gently west. The eastern and southeastern parts of the range are covered by later, more basic volcanic rocks which extend west from the Piute Range.

Several hundred old gold prospects occur near the new gold deposits in the southern part of the range. Most of the old workings consist of short shafts, adits or trenches but some are marked by extensive underground workings and large dumps. Two large open pit clay mines are located immediately west of the gold deposits. The clay pits are each about 1500 feet in diameter and one has been mined to a depth of about 200 feet. Numerous old pits, excavations and bulldozer trenches occur on the western side of the Castle Mountains and were made by prospectors exploring for other economic clay deposits within the extensive area of argillic alteration.

The structural geology of the Castle Mountains is not well-known. The range has a strong north-northeast trend as shown by the strike of the rock units and numerous fractures and silicified zones. Dips are shallow and usually to the west.

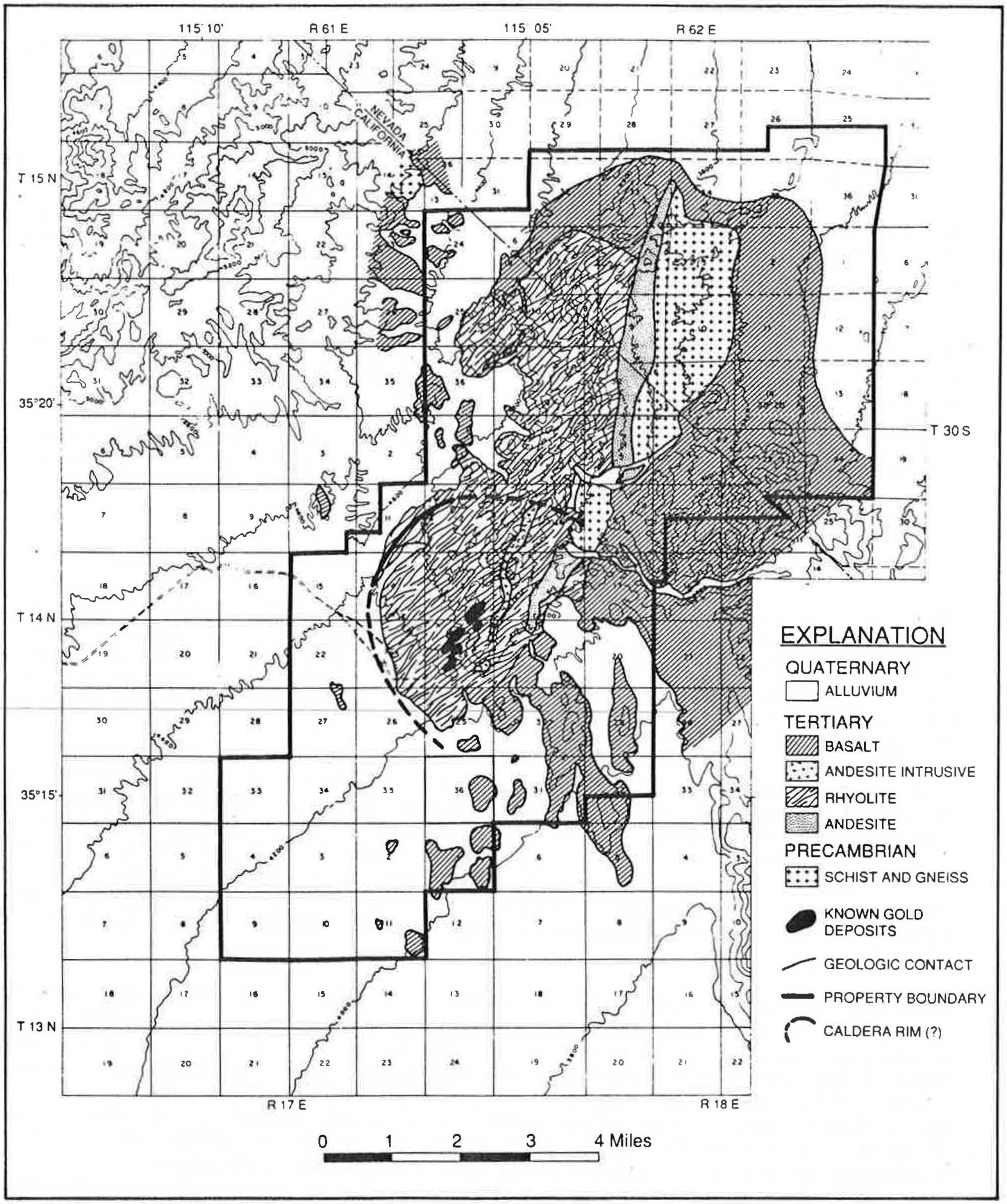

Fig. 5 Property and General Geologic Map

The range may be the western limb of a northeast-trending anticline whose axis extends through the window of Precambrian gneiss, as suggested by Hewitt (1956), but the evidence is not compelling. Low angle detachment structures which occur to the east near the Colorado River have not been observed in the Castle Mountains.

A series of arcuate, silicified and mineralized fractures form a zone about 1,500 feet wide and 7,000 feet long, 1-1/2 miles northwest of the deposits. These may be rim fractures of a small caldera, about 3-1/2 miles in diameter, which encloses the known mineralized area at the southern end of the Castle Mountains. Alternatively, this area may be the ring fracture zone of a small intrusive underlying the southern end of the Castle Mountains.

Another gold mining district, the Getchell, or Crater, is located on the eastern flank of Hackberry Mountain, about 20 miles south-southwest of the Castle Mountains, along the main north-northeast trend of mineralization (Fig. 4). One can speculate that the roughly circular Lanfair Valley is a large caldera and that a major north-northeast linear has localized gold mineralization at its intersections with the rim of the Lanfair caldera. These intersections may be marked by smaller rim calderas or by intrusive bodies at depth.

B. Detailed Geology

After discovery of the gold deposits, Viceroy began a geological investigation of the Castle Mountains with the hope that increased knowledge would assist in discovery of other gold deposits. Previous geological investigations in the Castle Mountains (Hewitt, 1956; Medall, 1964; Turner, 1985 and Ausburn, 1985) gave only the broad outlines of the geology. Viceroy carried out detailed geological mapping in the mineralized area (Watkins, 1987) and rotary drill cuttings and diamond drill core were logged in detail by Viceroy geologists (Moore, 1988). Viceroy also began a major geological investigation of the entire Castle Mountain range which continues to date (Capps, 1988). Specialized studies will also be undertaken in cooperation with the University of California-Riverside and others.

The results of these studies, of which this is only a brief overview, will be a significant contribution to the geologic understanding of not only the Castle Mountains and its gold deposits but of the entire Mohave Desert area of California. Viceroy has already collected, directly and indirectly, geological data which would cost several million dollars to duplicate. This data will in due course be published for the benefit of the general scientific community.

The Castle Mountains, like many ranges in the Mohave Desert, are composed of a Proterozoic basement unconformably overlain by Tertiary volcanic and sedimentary rocks (Figs. 6 and 7). The Tertiary rocks in the Castle Mountains are subdivided into pre- and post-mineralization groups. Preliminary results from an age

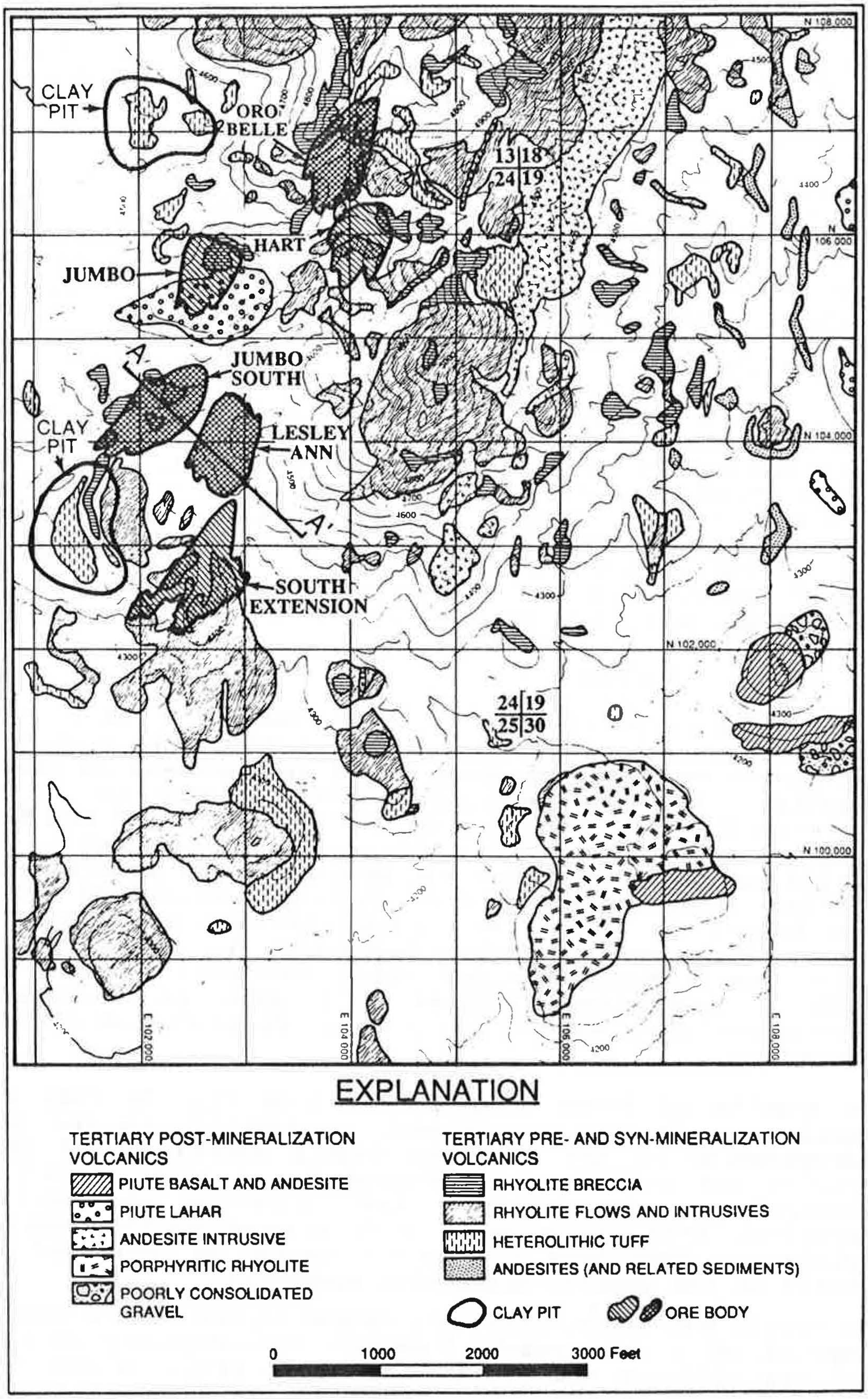

Fig. 6 Detailed Geologic Plan

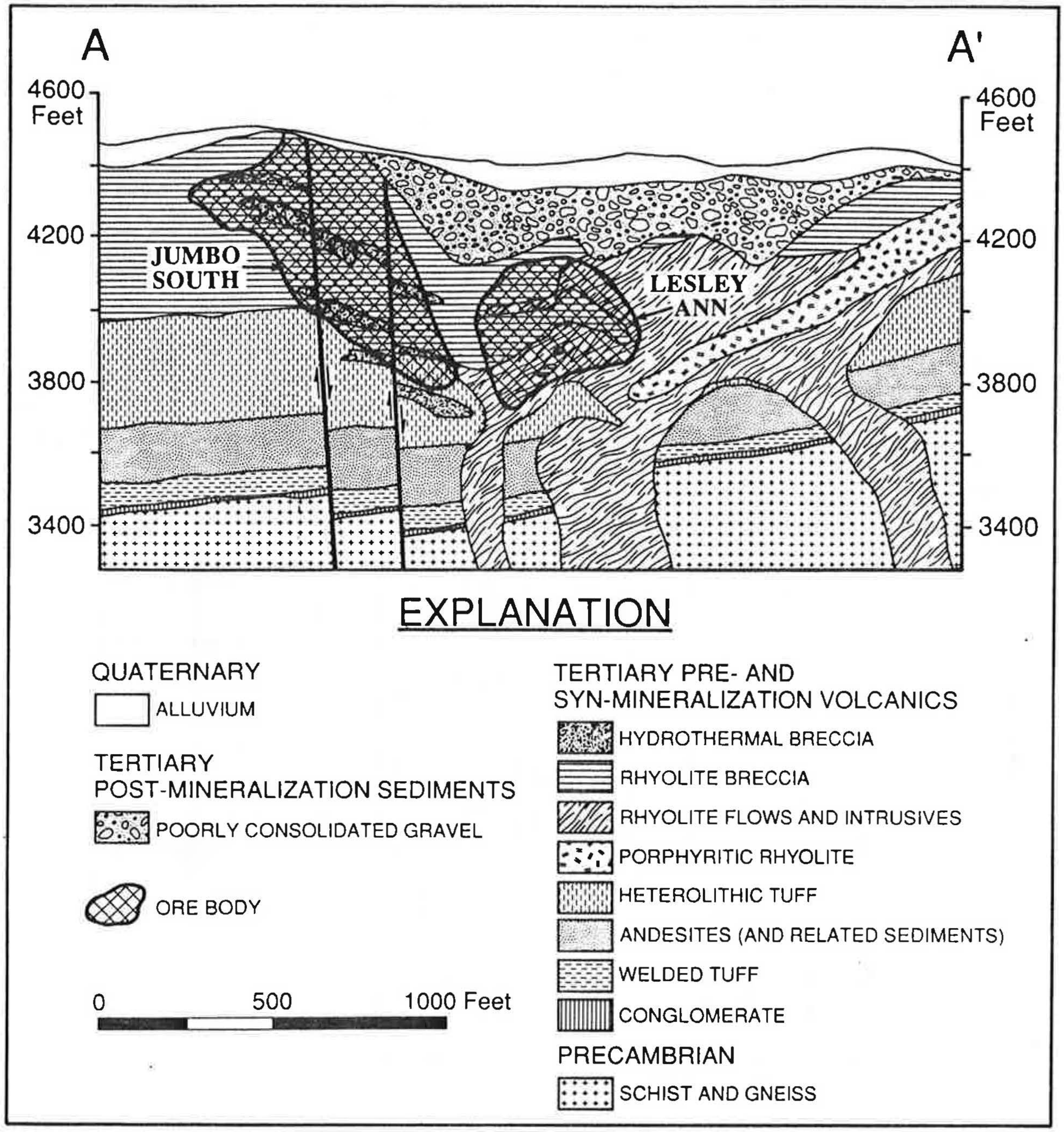

Fig. 7 Generalized Geologic Cross Section

dating program suggest that the Tertiary volcanics range in age from 22 to 13 M.Y. and that mineralizing events occurred about 15 M.Y. ago in mid-Miocene time (Table 2).

The metamorphic rocks are assumed to be part of the East Mohave basement complex that has been dated elsewhere at 1600 to 1800 M.Y. The basement is composed of foliated and layered high-grade metamorphic rocks and garnetiferous biotite and muscovite gneiss are the most common. Alaskite and amphibolite are present locally and a moderately foliated medium-grained granitoid intrusive occurs in isolated outcrops.

The Proterozoic rocks are commonly overlain by about 10 feet of pre-volcanic sedimentary conglomerate. The conglomerate is weakly indurated, light-and medium-greenish-gray, and poorly sorted. The moderately rounded clasts are composed entirely of Proterozoic metamorphics, up to 4 inches in diameter, and occur in a chloritic coarse sand matrix.

The basal conglomerate is overlain by a light pinkish-gray crystal-rich welded rhyolite ash-flow tuff. The tuff is generally pumiceous and moderately to strongly welded. Outcrop thickness varies from 20 to about 90 feet in the Castle Mountains and the ash-flow apparently filled topographic lows on the pre-volcanic surface. Biotite from the welded tuff has a K-Ar age of 22.3 +/- 0.7 M.Y. and sanidine has an age of 21.8 +/- 0.7 M.Y. (Table 2). The stratigraphic setting of this welded tuff suggests that it may correlate with the widespread Peach Springs tuff (Glazner, et al, 1986) but the 22 M.Y. age is older than the suggested age of 19.2 +/- 0.4 M.Y. (Nielson, Glazner and Lux, 1988).

PHASE DATED	LITHOLOGIC SETTING	LATITUDE LONGITUDE	REPORTED AGE (M.Y.)	NOTES
Whole rock	Piute trachy-andesite flow	35° 16' 29" N 115° 04' 31" W	13.0 +/- 0.6	1
Whole rock	Piute trachy-andesite clast	35° 16' 38" N 115° 04' 56" W	13.8 +/- 0.6	1
Illite-Sericite	Jumbo South deposit argillic alteration	35° 16' 54" N 115° 06' 08" W	14.9 +/- 0.3	2
Sanidine	Rhyolite welded ash-flow tuff	35° 17' 55" N 115° 04' 20" W	21.8 +/- 0.7	1
Biotite	Rhyolite welded ash-flow tuff	35° 17' 55" N 115° 04' 20" W	22.3 +/- 0.7	1

NOTES:
1 - Analysis by Geochron Labs, Cambridge, MA.
2 - Analysis by University of Arizona Isotope Geochemistry Lab

Table 2 New K-Ar age determinations in the Castle Mountains, California

Pre-mineralization volcanics above the welded tuff consist of about 200 feet of andesitic flows, tuffs and associated sediments overlain by as much as 1000 feet of rhyolite tuffs, flows, subvolcanic intrusives and associated flow-dome complexes.

Flows in the basal volcanics vary from latite to basalt but are generally andesitic. They are variably vesicular to amygdaloidal and are locally porphyritic. The associated volcaniclastic sedimentary rocks are medium grained arkosic volcanic sandstone and poorly sorted conglomerate with angular to rounded clasts of andesite, basalt and Precambrian

metamorphics up to 6 inches in diameter. Locally, the sediments are alluvial fan deposits, with graded beds averaging 1.5 feet thick. Poorly to moderately welded andesitic and minor rhyolitic lapilli tuffs are intercalated within the sediments and flows.

Rhyolite flow-dome complexes overlie the andesites and are surrounded by and intrude large thicknesses of rhyolite autoclastic breccia. This breccia is interpreted as crumble and flow breccia derived from the expanding domes. Most autobreccia has a tuff-sized matrix but lenticular beds of very coarse clast-supported rhyolite autobreccia occur locally. Although mineralization occurs in all of the older volcanic units, the rhyolite breccias host a large proportion of the mineralization and related hydrothermal brecciation, silicification and argillic alteration.

The rhyolite flow-dome complexes are characterized by vitrophyric and spherulitic zones near their margins and well-defined flow banding in the interior. At least three periods of pre-mineralization flow-dome formation are recognized. The first period was extruded onto the previously emplaced basal andesitic rocks and remnants of these early rhyolite domes tend to outcrop along the perimeter of the range. The second phase of flow-dome formation was preceded by the deposition of about 300 feet of heterolithic pyroclastic poorly-to non-welded rhyolite tuffs and volcaniclastic sediments, principally surge-related. Relatively porphyritic rhyolites intruded the heterolithic tuffs and locally domed them. The third and apparently final period of pre-mineralization rhyolitic volcanism capped the tuffs, early autobreccias and domes and produced more structural doming of the earlier volcanics. One rhyolite dome, named the "egg" for its prominent shape on aerial photographs, is central to many of the old workings. The vitrophyric basal contact of the third phase domes marks the position of the paleo-surface.

Silicified and silica-cemented hydrothermal breccias are common in the ore body areas where they are often associated with high-grade precious metal mineralization. Some breccia bodies are irregular in shape but others, hosted in silicified autoclastic breccias and heterolithic tuffs, are crudely stratiform in character. Hydrothermal breccias in flow-foliated rhyolites tend to follow the generally high-angle flow foliation.

Tertiary syn-and post-mineralization sediments unconformably overlie the early volcanics and filled paleovalleys during and after the mineralizing events. The sediments consist of unconsolidated, poorly consolidated, and poorly sorted gravels, boulder conglomerates and well sorted biotite-bearing arkose. The gravels and arkose are locally silicified and may contain ore grade mineralization.

These older rocks are intruded and unconformably overlain by post-mineralization Castle Mountain volcanic rocks including andesites, porphyritic latites and rhyolites. The latite dikes

cut mineralization in the central and eastern parts of the mineralized area. One of these subvolcanic latite dikes, on the eastern side of the range, is up to 500 feet thick and more than 2 miles long.

More recent mafic flows, agglomerates, associated lahars, and minor volcaniclastic sediments which form the Piute Range, to the east of the Castle Mountains, cover the eastern and southern extensions of the Castle Mountains. A trachy-andesite flow at the base of the Piute volcanics, near the southern end of the Castle Mountains, gave a K-Ar whole rock age of 13.0 +/- 0.6 M.Y. and a clast of similar rock in an agglomerate near the base of the Piute section gave a K-Ar whole rock age of 13.8 +/- 0.6 M.Y. (Table 2).

V. Mineralization

Gold mineralization is widespread over an area of at least two square miles and a vertical range of more than 1,500 feet, as shown by drilling and by old workings. Mineralization can be classified as volcanic-hosted epithermal and gold is the major metal present. The silver content is low and base metal sulfides are completely absent. The overall gold to silver ratio is about 1:2 but in the core of the deposits the ratio is reversed with a gold:silver ratio of 2:1.

In general, mineralization is related to permeability and occurs in brittle, well-fractured and brecciated rock units. Significant amounts of mineralization occur in all of the pre-mineralization Tertiary rock units but the rhyolite flow-dome complexes and derived breccias are more favorable than the lithic tuffs.

Mineralization was first thought to be controlled by a few north-northeast-trending, steeply east-dipping silicified zones which form prominent outcrops, as at the Oro Belle deposit. However, most reserves are in the relatively flat-lying, thick and laterally extensive Jumbo South and Lesley Ann deposits.

In detail, mineralization occurs chiefly in small hematitic, vuggy quartz veins and fractures or in silicified breccias. Most mineralization is very fine-grained and is not visible to the naked eye. However, some coarse gold occurs in shallow underground workings, as at the Oro Belle, and minor visible gold occurs in drill cuttings and core. Gold occurs as relatively pure grains and as electrum and is often associated with pyrite grains that have been oxidized to hematite. All ore reserves are in the oxidized zone and only rare sulfide grains occur above the water table, which is at a depth of about 550 feet. Metallurgical tests show that the ore is amenable to treatment by conventional heap leaching methods.

Silicification and argillization are the common forms of alteration. Gold is closely associated with silicification, which occurs pervasively and as numerous small chalcedonic veins and fracture fillings. Spectacular Liesegang rings often occur in mineralized rhyolite. Some of the best mineralization is related to relatively small zones of hydrothermal breccia. Mineralized rocks are generally bleached and show highly variable argillic alteration. Hydrothermal clay alteration taken from an underground working within the Jumbo South deposit gave a K-Ar date of 14.9 +/- 0.3 M.Y. on sericite-illite (Table 2). The two commercial clay pits immediately west of the gold deposits are probably part of a large-scale alteration zoning pattern but the details are not yet known.

VI. Mining

Viceroy plans an 8,000 tons per day (2,800,000 tons per year) open pit heap leach operation. Similar operations in California have recently been described in detail (Silva, 1988). Capital costs to place the Castle Mountain deposits into production are estimated at $35 million. The overall stripping ratio is 3 to 1 and gold recovery will be about 65%. Operating costs are projected to be about $200 per ounce of gold produced.

The ore will be broken by blasting in closely spaced drill holes and loaded by electric shovels or front end loaders onto 85 ton haul trucks and transported to the ore crusher. After crushing in three stages to less than 3/8" diameter, the ore will probably be agglomerated with cement and water to increase percolation, conveyed to the leach pad and stacked by conveyor in 20 foot lifts to a maximum height of 80 feet. The leach pad will be located on a gently sloping alluvial plain less than a mile southwest of the deposits. The pad base will be prepared from selected local soils which will be covered by a sealed synthetic liner protected by a geomembrane. The pad is designed to comply with the requirements of the Water Quality Control Board.

A weak cyanide solution will be added to water obtained from local wells and will be applied to the heap by means of drip irrigation at a rate of about 5 gallons per square foot per day. After percolating through the heaps, where the cyanide dissolves the gold, the gold-bearing solution will flow on a gentle slope beneath the ore to a corner of the leach pad where it will be collected and pumped to a treatment plant by way of a storage pond. The potential hazard posed by sodium cyanide is significantly diminished by the dilute concentration used and by the rapid natural degradation of cyanide in warm, sunny conditions and when the solution comes in contact with clay.

The gold-bearing solution passes by gravity through a series of tanks containing activated carbon granules, upon which the gold is absorbed. The barren solution is then recharged with cyanide, sent to the barren pond and back to the heap. This will be a "zero-discharge operation" in which all of the water

is recycled with the exception of evaporation losses and retention by the fines.

The gold-loaded carbon will be transferred to the carbon stripping facility where the gold will be stripped from the carbon. The carbon will be acid washed, reactivated by heat and returned to the circuit. The concentrated gold-bearing solution will be pumped through an electrolytic cell where the gold is deposited on steel wool. The gold-plated steel wool is melted in a furnace and poured into dore (gold-silver) bars. This product will be sold to a refinery for final processing.

The Viceroy Castle Mountain Project will provide about 150 jobs for at least 10 years and will have a major favorable impact on the economy of eastern San Bernardino County. The project will make a total annual contribution to the local economy of $17.5 million in payroll and through the purchase of supplies and services. Like all successful mining operations the project will also generate revenues for each of the three levels of government, local, State and Federal. Viceroy expects to pay up to $60 million in taxes during the ten year life span of the mine.

VII. Reclamation

Viceroy is a responsible corporate citizen and has agreed to a number of actions that will help identify and preserve archaeological and historical sites, increase public understanding of the desert, and protect the flora and fauna of the area. Viceroy will also carry out major reclamation programs to minimize the long term effects of the project.

Viceroy retained the Archaeological Research Unit of the University of California-Riverside to carry out an inventory of the archaeological and historical resources in and around the Castle Mountain project site. Project-related activities have been planned to reduce or eliminate any impacts on the archaeological and historical resources. For example, the initial leach pad areas were shifted several hundred yards to avoid the original Hart townsite and cemetery and some access roads were realigned to avoid archaeological sites.

Viceroy will pay for an information center for the benefit and enjoyment of visitors to the Hart Mining District. Themes will be developed with assistance from the Friends of the Mojave Road and the Bureau of Land Management. One important theme will be the role played by mining communities such as Hart in the settlement of the eastern portion of San Bernardino County. The center will include a description of mining techniques used in the early days and compare those to the modern techniques employed at the Castle Mountain operations.

Some of the vegetation that must unavoidably be disturbed by mining, principally Joshua Trees and cacti, will be transplanted to serve as nursery stock for revegetation of the area. Where possible, reclamation will be ongoing, rather than

being delayed until mining is completed. Reclamation efforts will include recontouring and revegetation of areas to blend into the surrounding terrain and eventual removal of all structures.

Viceroy will also undertake reclamation of many existing disturbed areas that have been created by over 75 years of mining in the area. It may even be possible to fill some of the existing clay pits with waste rock to lessen their visual impact on the environment. In many ways, the Castle Mountain area will show fewer signs of environmental damage after the new gold deposits have been mined than it does at present.

VIII. Summary and Conclusions

The new gold discovery of Viceroy Gold Corporation in the Castle Mountains will start the latest cycle of mining in the highly mineralized East Mohave Desert.

The original mining was carried out by Indians in Prehistoric times, probably for thousands of years, to obtain obsidian for arrowheads. Prospectors discovered high-grade gold in veins in the Castle Mountains in 1907, which led to a mining rush and a classic boom, but the outcropping veins did not carry high enough values at depth to be economic. Open-pit production of clay began in the 1920's and continues today, depending upon market demand.

The new gold mining cycle is based upon new technology and higher gold prices, which allow economic mining of lower grade ores. Also important are new geologic concepts which guide exploration for deposits at depth and for deposits that are completely concealed. Viceroy, with a combination of good geology and good luck, has discovered over 1 million ounces of gold in only two of its deposits, the Jumbo South and the Lesley Ann. The Jumbo South is located under and adjacent to an old, minor gold occurrence which is similar to hundreds, and perhaps thousands, of other gold occurrences in the California Mohave Desert. The Lesley Ann deposit is completely buried under 300 feet of gravel with no surface indication of mineralization. The "needle in a haystack" aspect of mineral exploration is shown by the fact that each of these deposits will fit inside a circle with a radius of only 500 feet.

The assessment of the mineral potential of an area is difficult and highly subjective at best. The Eastern Mohave Desert is known to be a highly mineralized area and there are probably many other gold deposits like those of the Castle Mountains located near old, minor occurrences or completely buried. Many mineral resources besides gold also occur in the Mohave Desert. It is important that responsible mineral exploration and mining be allowed to continue in the Eastern Mohave Desert so that the significant economic benefits can accrue to the people of California.

The Castle Mountain area of the East Mohave has been designated as a multiple use area in view of its known mineral potential. While the mineral potential is important, it is by no means the sole or exclusive resource. The area is also important for cattle ranching and contains wildlife, plant, water, cultural, visual and recreational resources. Viceroy's goal is to implement a mining project that is compatible with the continued use and enjoyment of the other resources, by employing sound environmental engineering practices in the design, construction and operation of the Castle Mountain Project.

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OVERVIEW OF THE STANDARD HILL GOLD MINE
MOJAVE, CALIFORNIA

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ABSTRACT

The Standard Hill Mine is a small open-pit heap-leach gold mine operated by Billiton Exploration, U.S.A. It is located in the Mojave Mining District, about 100 miles north of Los Angeles. Mining has occurred at Standard Hill on an intermittent basis since 1894, with a total production estimated at 150,000 ounces of gold and 500,000 ounces of silver. The country rock consists of Mesozoic-age quartz monzonite which has been intruded by Miocene-age porphyritic quartz latite. Precious metal mineralization is hosted by quartz-calcite veins which commonly occur at or near the contact of the two rock types. Selective mining is performed using conventional drilling, blasting and mucking procedures. Ore control has proved to be a challenge due to the narrowness of the veins. About 2000 tons per day of ore are crushed to minus 3/8-inch size, agglomerated and stacked into heaps. A solution of sodium cyanide is used to dissolve gold and silver from the heap. The precious metals are recovered using a portable process plant. other small precious metal deposits amenable to heap leaching occur throughout the California desert.

INTRODUCTION

The Standard Hill Mine is a small open-pit heap-leach gold mine operated by Billiton Exploration, U.S.A. It is located in the Mojave Mining District about 100 miles north of Los Angeles, California. The Standard Hill Mine is part of the Standard Group (Troxel and Morton, 1962) which has also been known as Bowers Hill (Tucker and Sampson, 1933) and Elephant Butte (Julihn and Horton, 1937).

The first discovery of gold in the Mojave Mining District was in 1894 at the Yellow Rover vein on Standard Hill. Soon afterwards the other veins in the vicinity were discovered and developed. In 1901 a 20-stamp mill and 60-ton cyanide plant were built. DeKalb (1907) reports that during the years 1903 to 1907 the Exposed Treasure vein produced one percent of the total gold and silver production for all of California.

The main mining was done between 1901 and 1915, and then from 1921 to 1928, when a disastrous fire destroyed the mill and surface plant (Tucker and Sampson, 1933), After 1928 mining was continued on an intermittent basis until 1956.

The total historic value of gold and silver produced from Standard Hill is estimated to be $3.5 million (about 150,000 ounces of gold and 500,000 ounces of silver). Seventy to 85 percent of this total is credited to the Exposed Treasure vein (Troxel and Morton, 1962).

Billiton acquired a mineral lease on the property and began mapping and sampling the area in 1983. One quarter of the original 250 rock chip samples contained over 0.03 oz/ton gold. The best gold values were found within an 80-acre area covering the central part of Standard Hill which includes the three major veins. The 178 rock chip samples collected in this central area averaged 0.062 oz/ton gold. Significant gold mineralization was outlined during several phases of drilling throughout 1983 and 1984.

The initial feasibility study was completed during the springof 1985, and additional predevelopment drilling was performed during late 1985 and early 1986. The permitting process and metallurgical testing was initiated during this same time period. By February 1987, contracts, operational plans and Permits had been finalized. On-site construction began in March. By May Billiton began to mine ore and the first precious metal pour occurred on July 21, 1987.

GENERAL GEOLOGY

Standard Hill consists of Mesozoic-age quartz monzonite which has been intruded by Tertiary-age volcanics. The quartz monzonite is of Sierra Nevadan age and extensive exposures are found in the Tehachapi Mountains ten miles to the northwest. The quartz monzonite is a light to medium gray, medium-grained variety which disintegrates to a typical light brown grus.

The Tertiary rocks are part of the Gem Hill Formation of the Tropico group as described by Dibblee (1963). The intrusives are identified as the Bobtail Member of the Gem Hill Formation. Age of this intrusive phase is commonly considered to be middle Miocene and is related to the extensive volcanic activity centered at Soledad Mountain two miles to the south (Perez, 1978). The topographically higher parts of Standard Hill are underlain by the more resistant quartz latite. The intrusive contact between the latite and monzonite is usually sharp. Latite dikes occasionally show a narrow chill margin.

The main part of Standard Hill is underlain by a northwest trending funnel-shaped intrusion of light brown porphyritic quartz latite. Here the feldspar and quartz phenocrysts are larger and more numerous than elsewhere on the hill. Dike-like features are formed by the quartz latite at both the northern and southern ends of this exposure.

The southeast portion of the hill consists of a series of dikes and fingers of dark brown porphyritic quartz latite that trend north to northwest. These are typically 50 to 100 feet thick. Locally the quartz latite forms circular outcrops with a brecciated appearance, resembling a plug, exposures created during recent mining operations revealed numerous small xenoliths of quartz monzonite in the margins of one plug.

HISTORIC MINING

The largest and most extensively developed vein on Standard Hill is the Exposed Treasure, traceable for over 2600 feet along the western side of the main hill. The southern end of the Exposed Treasure vein strikes due north along a quartz latite dike, then tends northwestward, skirting the higher parts of the hill. At the bend a wide breccia zone is developed which corresponds with a large oreshoot.

Mining in the Exposed Treasure vein extended to the 900-foot level along the dip of the vein. There were over 10,000 feet of drifts and stopes present. The high-grade vein ranges from two to twenty feet thick, averaging five feet. The average ore grade was probably about 0.3 oz/ton gold.

Along its surface trace the Exposed Treasure vein dips 40 to 60 degrees east. Average dip of the vein in the active pit is 45 degrees east. The dip lessens with depth. At the 900-foot level of the old workings the vein dips only 25 degrees east.

The Yellow Rover-Golden Carrier vein system extends for over 1500 feet along the crest and western side of southeastern Standard Hill. It consists of a series of vein splays which cover an area up to 200 feet wide. The veins change strike from due north to N 50 W, dipping generally 60 degrees to the east at the surface. The high-grade portions of the veins were one to three feet wide and mined to depths of 300 feet on the incline.

The Desert Queen vein is unusual because it trends in a N 15 E direction off the northeast side of Standard Hill. The Desert Queen vein was traceable on the surface for over 1100 feet, and present mining has shown this vein to extend another 500 feet along strike. At the surface it dips 40 to 60 degrees east. The average dip of the vein in the active Desert Queen pit is 45 degrees east.

The high-grade portion of the Desert Queen vein varied in thickness from two to six feet. Old workings included a 400-foot inclined shaft and over 3000 feet of drifts.

MINERAL OCCURRENCE

Precious metal mineralization is hosted by quartz-calcite veins that generally trend north to northwest and dip moderately to the east. The veins most commonly occur at or near the contact of the monzonite with the latite. The hanging and footwall contacts of the veins are usually quite sharp and visibly distinct.

Neither rock type shows a preference for hosting the veins, although on the southeastern part of the hill the numerous veins do tend to wrap around the brecciated quartz latite plugs. The few places a stockwork of veinlets are encountered are hosted by quartz monzonite. The veins appear to have filled pre-existing fractures, as the majority of unmineralized fractures trend this same direction. Only minimal post-mineralization faulting has been observed.

Alteration of the host rocks is only present directly adjacent to the veins. Where observed this occurs as argillization and sericitization, usually of the quartz monzonite, occasional narrow zones of silicification adjacent to the veins have been observed during mining.

Selective sampling of the vein material has shown that the gold is usually hosted by the silica rather than the calcite. The silica ranges from small gray quartz veinlets to larger masses of drusy or granular vein filling. Terminated quartz crystals and other evidence of open-space filling is common.

The calcite is a dark reddish-brown stained variety, containing abundant iron and manganese oxides. In places the carbonate has been completely removed by weathering, leaving only a spongy mass of dark brown oxide material.

The veins at Standard Hill are deeply oxidized and contain only a trace of pyrite. Occasionally a trace of copper oxides can be found.

Fluid inclusions in the quartz vein material show a range in temperature of formation from 200 to 300 degrees C. It appears that the calcite probably formed during a later, lower temperature stage than the quartz.

Although numerous high-grade blastholes (> 0.6 oz/ton) have been encountered during mining, the gold itself is only rarely visible. Scanning electron microscope work from some higher-grade ore revealed gold occurring as coarse (50 micron) blebs which occasionally contain some silver.

The average silver:gold ratio over the life of the open pit mining has been 6:1. The monthly silver:gold ratio has ranged from 2.5:1 up to 11:1. Tucker and Sampson (1933) report silver occurring as cerargyrite changing to argentite with depth. Based on crusher assays, the silver appears to have a bimodal distribution with respect to gold. One phase of silver mineralization is associated with the gold, whereas the other phase is relatively gold depleted. The age relationship between these two phases is unknown.

The width of the vein pinches and swells both along strike and down dip. Ore zones (> 0.03 oz/ton) range from ten up to 80 feet wide. Along the strike of the Desert Queen vein six zones which form ore shoots of higher-grade ore (> 0.1 oz/ton) occur, generally every 200 to 300 feet. These zones typically are 20 to 30 feet wide and at least 60 feet long, although usually not over 100 feet long on any bench. The lengths of individual ore shoots are quite variable on a bench-by-bench basis.

These higher-grade zones are easily traceable vertically from bench to bench. The most extensively mined ore shoot is traceable through 12 benches. Between ore shoots are lower-grade material commonly running 0.03 to 0.05 oz/ton. Ore shoots amount to about 15 Percent of the total vein mined, yet they account for 30 percent of the ounces sent to the crusher. Recognition of this poddy nature of the mineralization is important in evaluating vein-type deposits.

OPERATIONS

Billiton elected to use contractors for most of the labor force. Billiton owns the crushing equipment and process plant, and contractors supply the labor. The mining contractor uses his own equipment. At its maximum Billiton had on-site just four full-time personnel: mine manager, plant superintendent, mining engineer and geologist. Total capital costs for crushing equipment, process plant and heap liner, amounted to $2.7 million.

Standard Hill is mined using conventional drilling, blasting and mucking procedures. Bench height is 15 feet and blastholes are drilled on a 12- by 12-foot diamond pattern. ANFO is the blasting agent. A 25-foot catch bench is left every fourth bench. Theoperations are active in two pits. The larger pit is along the Desert Queen vein on the eastern side of Standard Hill. The pit is 1700 feet long and nearly 300 feet deep. About 80 percent of the total production has come from the Desert Queen pit. The smaller pit extends 600 feet along the Exposed Treasure vein. It is 150 feet deep.

The primary method of ore control begins by collecting cuttings from the blastholes. The cuttings are analyzed on site using a two hour cold-cyanide shake, and the gold content is determined by atomic absorption. Blastholes are surveyed, and holes containing ore grade mineralization are relocated after the blast.

Rock which assays 0.033 oz/ton or greater is sent to the crusher as ore. Low-grade rock runs from 0.026 to 0.032 oz/ton and is segregated in a low-grade stockpile. Rock that assays less than 0.025 oz/ton is considered waste. Once mining ceases in 1989 and the low-grade stockpile is processed, close to 900,000 tons of ore will have been put on the heap. The overall strip ratio has been 5:1.

Two front-end loaders are used to move the shot rock. A Cat 988 with a seven cubic-yard bucket is used primarily for loading ore, and a Cat 992 with a 14 cubic-yard bucket is used for loading waste.

The ore is reduced to minus 3/8-inch size using a jaw, cone and roll crusher system. About 2000 tons per day are crushed. The average monthly grade of rock through the crusher ranges from 0.055 to 0.060 oz/ton gold and 0.3 oz/ton silver.

The material is agglomerated with cement and stacked in 30-foot high heaps using a radial arm stacker. Cyanide solution is sprinkled on the heaps, dissolving the gold and silver. The heaps are built upon a pad which has a 40-mil lower liner and a 60-mil upper liner. The pad was constructed so that any solutions which might breach the upper liner will be collected in sumps between the upper and lower liners and then pumped out. A moisture detection system was installed beneath the lower liner

to insure no fluids pass into the soil. In addition there are groundwater monitor wells around the pad which are periodically sampled.

Auger sampling of depleted portions of the first heap has shown recoveries of 70 percent for gold and 60 percent for silver. Complete leaching takes about six months.

The precious metals are recovered from the cyanide solution in a portable process plant using tanks of activated carbon. The barren cyanide solution is then pumped back out onto the heap, completing the cycle in this closed system.

The concentrated gold and silver are stripped from the carbon limits set by Lahonton Regional Water Qualily Control Board.

Upon completion of the leaching cycle the heaps will be flushed for detoxification to bring the cyanide level down to within the limits set by Lahonton Regional Water Quality Control Board.

ORE CONTROL

Ore control has proved to be a challenge due to the narrowness of the veins in combination with the somewhat erratic nature of the gold mineralization. The complete mining and milling sequence was examined to see what changes could be made to improve the ore control process. Listed below are a number of enhancements which helped increase the average grade of ore sent through the crusher from 0.049 to 0.067 oz/ton.

Blasting

Because the veins are narrow, any movement during blasting could result in dilution. A study was undertaken to measure the actual amount of horizontal movement experienced during a blast. Test holes were drilled within the regular blast pattern and filled with small white cloth sample bags which had been filled with drill cuttings. The holes were surveyed prior to the blast and then relocated with stakes after the blast. When mucking operations neared the site of each stake, care was taken so that the resulting positions of the bags could be compared to the original. Substantial movement occurred during a blast (four to eight feet horizontally), so the surface delay pattern was changed to reduce ,his to a maximum of two feet.

Ore Determination

Geochemical analysis of blasthole cuttings is the primary method for determining ore, low-grade and waste. Originally each blasthole was considered to be at the center of a mining block, and the grade for that block was taken as the value of the blasthole. Experience has shown, however, that this is a simplification and not always indicative of the nature of this deposit. This is especially true when dealing with gold values near the cutoff grade and blastholes along the edges of the veins.

The method of ore determination was changed so that the mining block now has a blasthole at each corner and the grade of the block is considered to be the average of the four blastholes. Such blocks are aligned along the strike of the veins. From observation during mining it appears that this method better reflects the actual location of the mineralization. This change resulted in a significant increase in the average crusher grade. Comparison of this four-corner method with the geostatistical method of kriging shows a close correlation.

Selective Mining

The quartz-calcite veins, although relatively narrow, are generally not difficult to visually distinguish from barren wallrock. Detailed mapping and sampling early in the life of the mine demonstrated what features were indicative of veins hosting gold mineralization. One of the primary responsibilities of the mine geologist is to teach these visual keys to loader operators and other individuals.

Because sight is useful, every attempt is made to load oreduring daylight hours, and the geologist or day shift foreman is usually present to direct the loading operations. Tests during mining have also determined that the Cat 988 front-end loader with the smaller bucket leads to greater selectivity when loading ore.

Oversize Rock

Boulders of rock which are over three feet in diameter are segregated at the ore stockpile for further breaking before going into the jaw crusher. This segregation allows the mine geologist to visually inspect the oversized material. Any boulders which appear not to be ore material are marked and isolated as waste.

Sampling procedure

Proper sampling of both blastholes and the crusher material is complicated by the erratic nature of gold, its relatively low concentrations (parts per million) even at ore grades, and its high density. These factors combine to produce biased samples with low reproducibility. A study of 150 duplicate crusher samples showed a correlation coefficient of only 0.3.

Mining in the pit is guided in a general way by blasthole assays, but specific loads are directed to the ore stockpile, low-grade stockpile or waste dump as much by visual judgement as by specific geochemical assays. This requires detailed geologic interpretation of the vein structure. Careful monitoring of crusher assays is necessary so that these assays can be correlated to specific rock and vein material going through the crusher.

An automatic sampler has been installed at the crusher, and tenpound sample of material is collected about every 75 tons. This allows a weighted average to be calculated on a daily basis which is based upon at least 25 to 30 individual samples. Although the confidence in the assay of any one sample may be low, the increased number of samples gives good confidence of the calculated daily ore average. During an 11-week period over 950 crusher samples were collected and analyzed. The average ore grade over this period was calculated to be 0.059 oz/ton gold, with a 95 percent confidence that the true mean is within 0.004 oz/ton of this average.

CONCLUSIONS

Gold can be difficult to mine due to theparticulars of its occurrence. Selective mining methods along with rigorous sampling and detailed geologic interpretations have been shown to be effective in addressing these difficulties at Standard Hill.

Other oxidized veins which would constitute small precious metal deposits amenable to heap leaching occur throughout the California desert. A number of geologic issues need to be addressed when evaluating the open pit potential of these types of deposits. Two major issues are:

1) From the beginning it must be recognized that the mineralization occurs as ore shoots within veins. The ore shoots supply a significantly higher percentage of the total gold ounces than their percent volume of the vein. The exploration and delineation drilling must be done with this in mind. The modeling of ore shoots is difficult without numerous closely-spaced drill holes, a very costly item.
2) A rigorous sampling program should be established early in the property evaluation so both geologists and engineers can have similar confidence in the ore reserves which are generated. Also, the problem of extremely high-grade samples and how much influence they are to be given must be resolved.

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RELATIONSHIP BETWEEN EXTENSIONAL TECTONISM AND SILVER-BARITE MINERALIZATION OF THE CALICO MINING DISTRICT, SAN BERNARDINO COUNTY, CALIFORNIA

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ABSTRACT

The Calico Mining District has produced over $20,000,000 of silver ore, much of it from 1880 to 1900, ranking the district as the largest silver producer in California. Silver-barite mineralization occurs in both the lower Miocene Pickhandle volcanics and the overlying sedimentary middle Miocene Barstow Formation. The style of mineralization is remarkably similar in both formations, but structural controls and mineral distribution differ significantly.

The earliest veins in the Pickhandle Volcanics consist of barite and jasperoid, followed by a second stage of barite, jasperoid, oxides and sulfides. Subsequent oxidation of some of these veins by circulating meteoric water resulted in the formation of secondary oxides, carbonates and silver chlorides. Mineralization in the Barstow Formation, in contrast, is largely disseminated with veins accounting for only a percent or so of the total. However, paragenesis of the vein minerals in the Barstow closely parallels that in the Pickhandle with Early Barite Veins followed by Silver-Silicification Veins and Late Calcite Veins.

A model is proposed which invokes ground preparation during early Miocene detachment faulting followed by hydrothermal emplacement during middle Miocene time of vein mineralization in fracture zones in the Pickhandle Formation and disseminated mineralization in the Barstow Formation. This was followed by reactivation and additional dilation of some fractures reflecting a regional, post-Barstow, distributive, dextral shear system. Subsequently oxidizing meteoric waters altered existing mineralization and deposited secondary oxides and jasperoid.

HISTORY

The colorful history of the Calico Mining District has been described by many authors; Weber (1966) provides an excellent summary. The district flourished from the 1880's to the close of the nineteenth century. The manpower shortage and downturn in mining

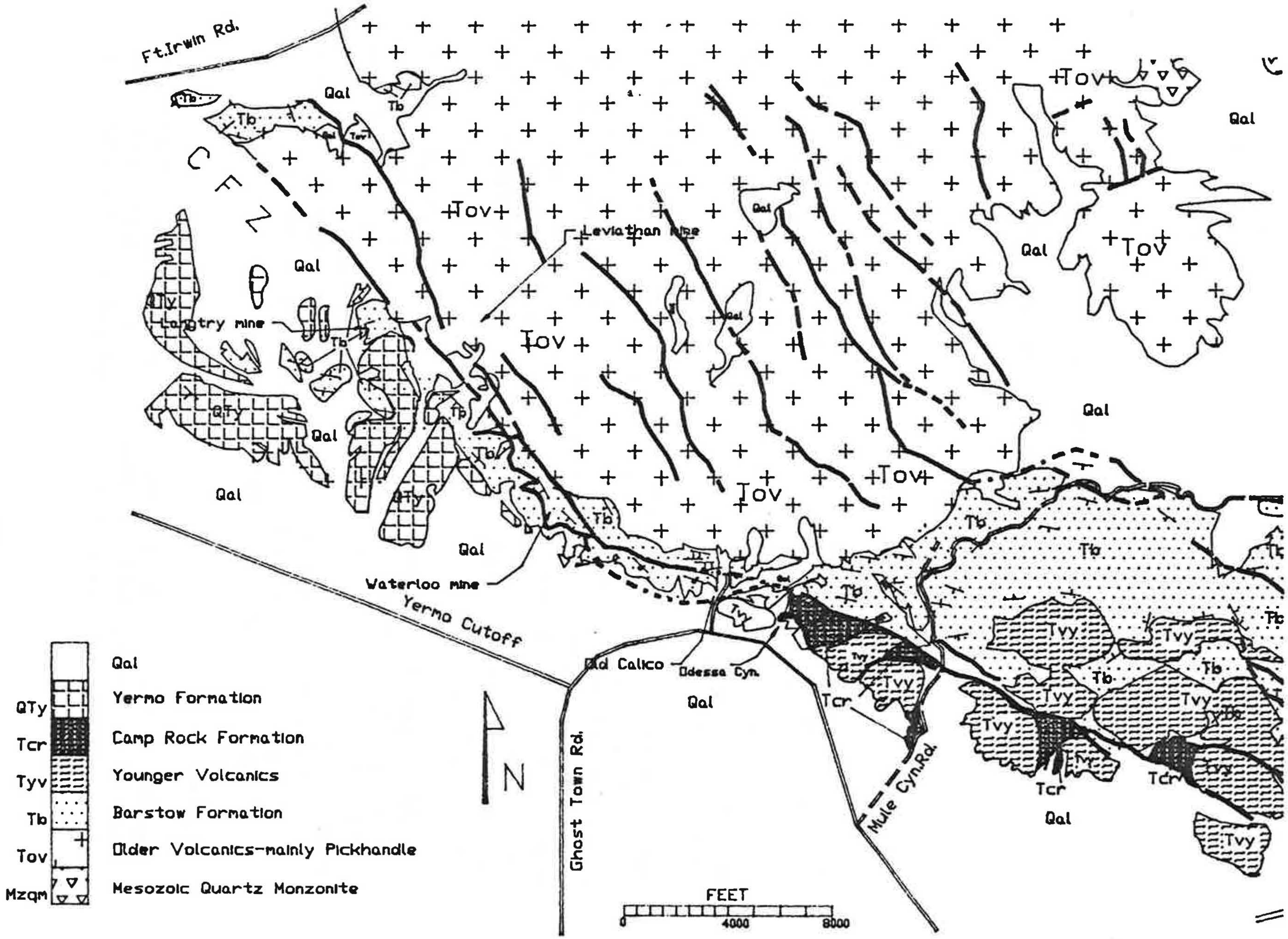

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Figure 1

STRATIGRAPHIC SECTION

Calico Mountains

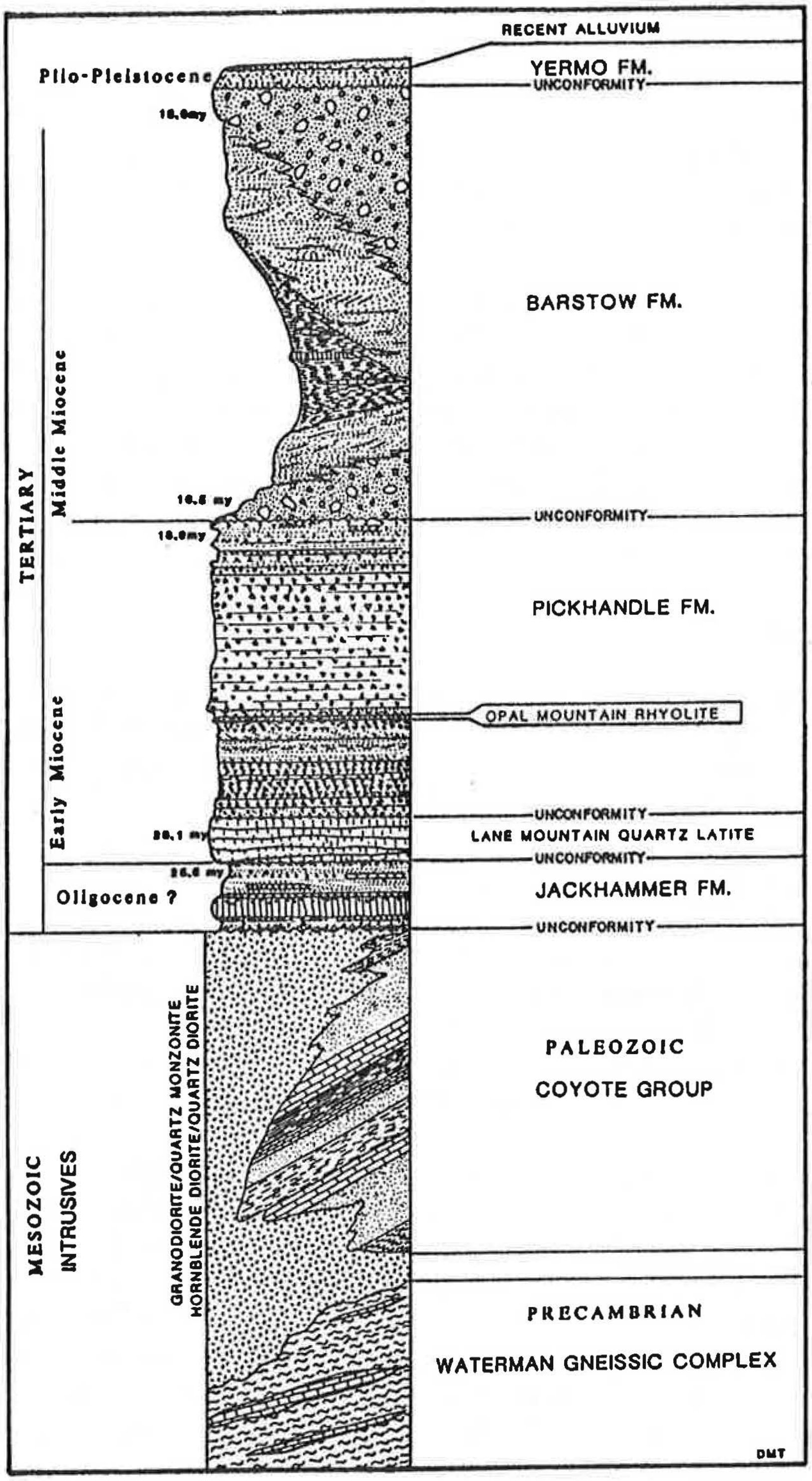


Figure 2

during World War I and the subsequent Great Depression marked the end of significant activity, but not before the district had established itself as the largest silver producer in California. Total production prior to 1940 is thought to have exceeded $20,000,000.

During the 1950's an economic boom and a renewed interest in silver briefly resulted in the reopening of several of the district's mines, but production was small. Accelerated petroleum exploration in California, however, made barite an economically attractive commodity. From 1957 to 1961 the Leviathan Mine, a few kilometers to the northwest of Wall Street Canyon, center of much of the nineteenth century activity, was the largest barite producer on the west coast. Inasmuch as substantial barite reserves remain, the deposit represents a significant mineral resource.

In the early 1960's, ASARCO Inc. began the exploration and limited development of a disseminated silver deposit along the southwest flank of the Calico Mountains. The Waterloo Project, as it was named, is reported to contain approximately 45MT of ore grading 3-4 troy ounces per ton silver and 10% barite. A related smaller deposit, the Langtry, lies about four kilometers northwest of the Waterloo. Reserves in this deposit are reported to be 15 MT grading 2-2.5 troy ounces per ton silver. Subsequent development has been hampered by environmental concerns and by the long-term depressed silver prices. The property has been inactive for nearly a decade.

GENERAL GEOLOGY

Various portions of the Calico Mining District have been mapped by DeLeen (1950), McCulloh (1952,1965), Weber (1965), Dibblee (1967), Mero (1972) and more recently by Fletcher (1986), Jessey (1986), Payne and Glass (1987), Jessey and Marvin (1988) and Tarman and Thompson (1988).

The Waterman Gneiss (Fig. 2), exposed to the southwest of the Calico Mountains, in the Mitchell Range and Waterman Hills is the oldest rock unit in the region. Like many of the Cordilleran metamorphic core complexes the age of the rocks of the metamorphic infrastructure remains controversial. It has been suggested to be of Precambrian, Paleozoic or early Mesozoic age by various authors. No Waterman Gneiss is known to outcrop within the Calico Mining District, however clasts of metamorphic rock are common within volcaniclastic units of the Pickhandle Formation.

Over 7000 meters of metasedimentary rocks collectively called the Coyote Group by McCulloh (1952) crop out along the northern margins of the Calico Mountains. Poorly preserved fusilinids found in the lower portions of this section indicate some of the rocks, at least, to be of Paleozoic age (Rich, 1971). The Coyote Group consists of carbonates and fine to coarse grained siliciclastic rocks with significant thicknesses of volcanics ranging from latite to basalt intercalated within some portions of the section. Many of the exposures are intruded by granitoid dikes. Neither the top or the bottom of the Coyote Group is exposed in the area around the Calico Mountains.

Granitic to dioritic intrusive rocks of Mesozoic age are exposed along the eastern and northeastern margins (Fig. 1) of the Calico Mountains east of the Calico Mining District. While no major outcrops of intrusives occur within the district itself, exotic blocks of quartz diorite ranging from centimeters to tens of meters in diameter have been noted at many localities, particularly to the northwest of Wall Street Canyon. These are interpreted to be blocks of subjacent wall rock rafted vertically by upward moving volcanic material.

The early Miocene Pickhandle Formation is one of two major ore hosts in the district. Most of the vein-type barite-silver mineralization occurs within this formation. In general the Pickhandle consists of a series of intercalated pyroclastics, volcanic breccia and volcanic flows, the latter, although ranging from rhyolite to andesite, are predominantly dacitic. Minor sedimentary units with volcaniclastic components occur throughout the sequence, but are more common near the contact with the overlying Barstow Formation.

In many places the middle Miocene Barstow Formation unconformably overlies the Pickhandle volcanics, the basal contact marked by the abrupt transition from volcanics to sedimentary rocks. In several places, however, a conformable relationship appears to be evidenced with tuffaceous redbeds marking the transition between the two units. The Barstow consists predominantly of interbedded shales, siltstones, sandstones and conglomerates with minor fresh water limestone and finer grained siliciclastic sedimentary rocks more prominent in the basal part of the section. The lowermost sedimentary units also contain more prominent volcaniclastic components than do the upper units. The Barstow Formation is the second major ore host within the district. Ores are generally low grade disseminations and randomly oriented stockwork veins of barite and various silver minerals.

Dibblee (1970) identified younger, post-Barstow andesitic and dacitic volcanics locally capping the Pickhandle and Barstow Formations. These younger flows are generally confined to the eastern portions of the Calico Mountains. They are cut by the Calico fault. No evidence of mineralization has been found in any of the younger volcanics.

McCulloh (1952) mapped local occurrences of unconsolidated gravels cropping out mainly on the periphery of the Calico Mountains. The term Yermo formation has been loosely applied to the gravels and a tentative Pleistocene age has been assigned, based on their similarity to other Pleistocene gravels occurring throughout the Mojave. Clasts within the Yermo are dominantly volcanic with an occasional granitoid fragment present.

The Calico Fault Zone is the major structural feature within the district. It lies along the southwest flank of the Calico Mountain block, striking from N70W to N40W. It is one of several northwest striking, right slip faults affecting the Mojave Desert province.

The Calico Mountains are part of a large northwest plunging anticlinorium, itself folded into a series of synclines and anticlines with northwest plunges. The coincidence between trends of the Calico Fault Zone and fold axes may indicate a genetic relationship.

Barite veins within the Pickhandle volcanics are controlled, for the most part, by a series of northwest striking, subparallel, high-angle faults bearing striae raking at large angles to strike, most clustering around 90 degrees. A few veins can be observed, however, bearing kinematic indicators reflecting reactivated subhorizontal fault motion. All veins trend N 20-80 W, with the majority approximating the N 60 W strike of the Calico Fault itself.

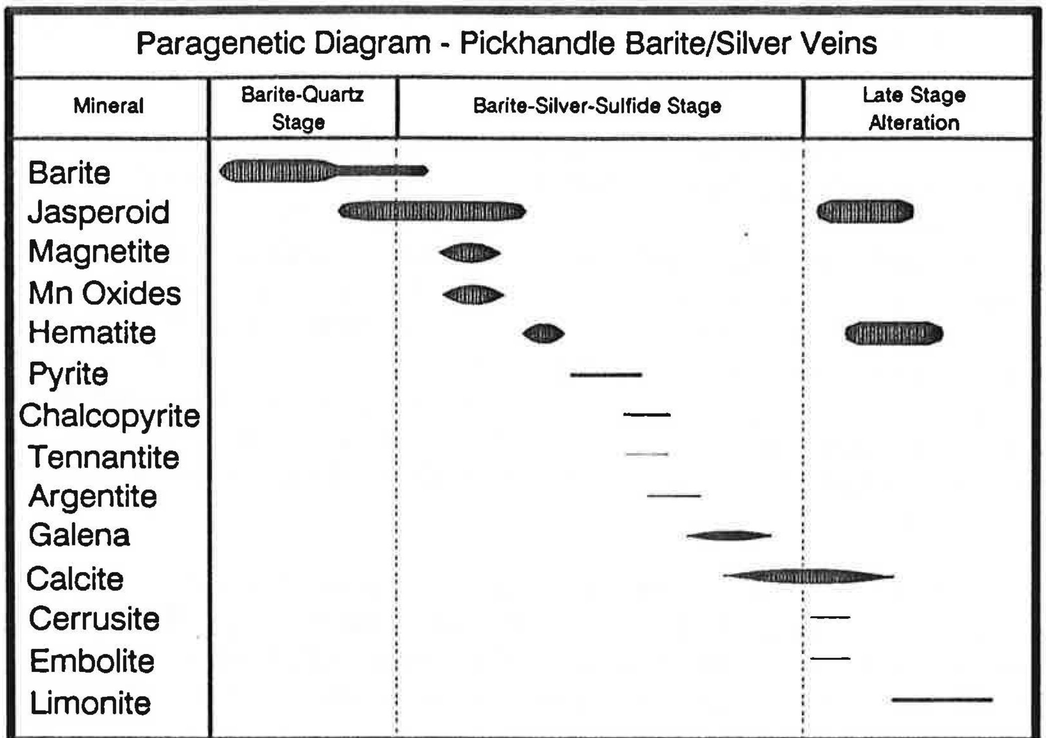


Fig.3 Paragenetic sequence - Pickhandle vein mineralization

BARITE-SILVER MINERALIZATION

Two distinct types of barite-silver mineralization occur within the district. Vein-type deposits are extensive within the Pickhandle volcanics and have accounted for much of the past production, particularly from deeply oxidized, near surface outcrops in the vicinity of Wall Street Canyon. Embolite constituted the main ore mineral with lesser cerargyrite and native silver. Disseminated to stockwork vein deposits of low grade silver-barite mineralization also exist within the sedimentary units of the Barstow Formation. These have been described by Fletcher (1986) and subsequent discussions of this mineralization is taken largely from that reference.

Pickhandle Barite-Silver Veins

Five recognizable end member, vein types can be mapped (Jessey, 1986). Of these, only two are common. Gradations exist between all vein types. Figure 3 is a generalized paragenetic sequence for the Pickhandle barite-silver veins. Note the similarity to that published by Fletcher (1986) (see below) for the mineralization in the Barstow Formation. Clearly, there is a marked similarity between the mineralization in both formations.

Black matrix barite veins

The most common vein type, termed the black matrix barite vein, consists of brecciated barite fragments in a matrix of iron and manganese oxides and minor calcite and sulfides (Fig. 4). In general the barite is highly fractured, although occasional unbrecciated veins can be observed. Calcite is quite rare, paragenetically much later than barite and often quite dark due to the presence of included phases, identified as iron and manganese oxides by the U.S. Bureau of Mines (Hubbard,pers. comm., 1984).

Interstices between barite fragments are most commonly filled with a mixture of iron and manganese oxides (Fig. 5). Magnetite occurs in many samples, with partial to total alteration to hematite common. Some secondary

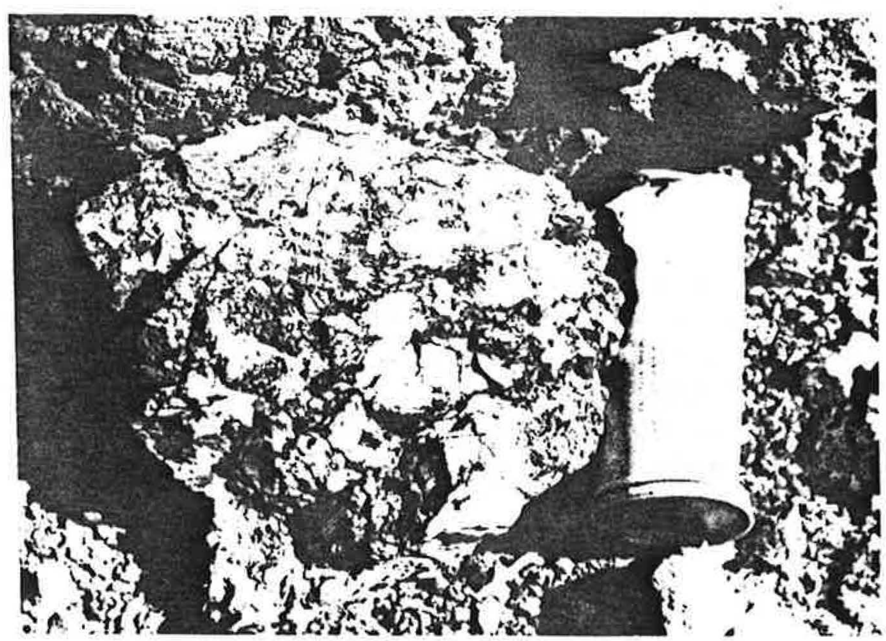


Fig. 4 Black matrix barite vein with fragmented barite crystals (white) in a matrix of iron and manganese oxides, sulfides

limonitic veins are occasionally present, related to recent oxidation of the host rock. Manganese oxides are common in most samples, but cannot be differentiated by simple microscopic analysis. It would appear, nonetheless, that several varieties of manganese oxide are present.

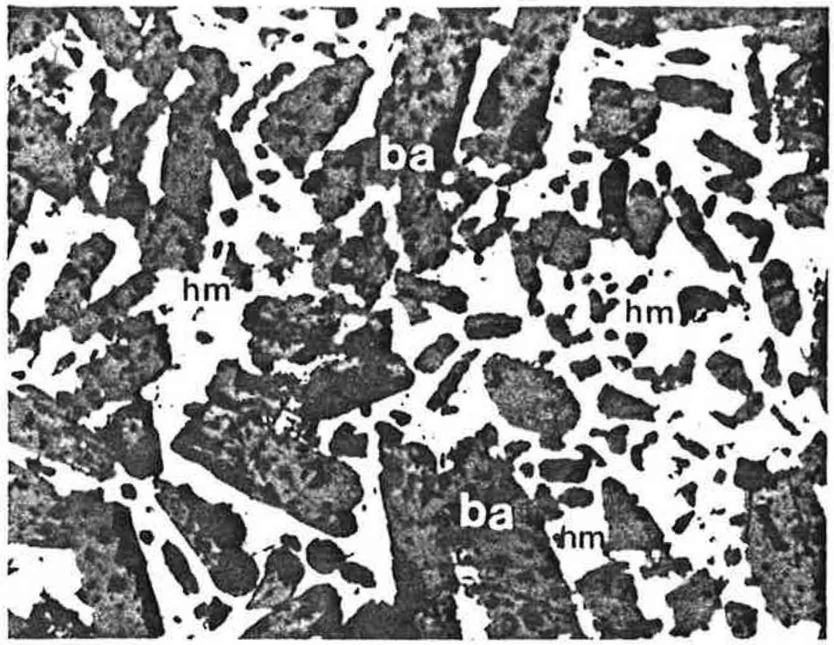


Fig. 5 Photomicrograph of a typical black matrix barite vein. Barite (ba) occurs as euhedral grains partially replaced by later hematite (hm). (50X)

Sulfides are volumetrically quite rare. The most common are pyrite and galena (Figs. 6 and 7) with trace chalcopyrite and tennantite. Silver assays as high as 1100 ounces per ton have been reported (Hubbard, pers. comm., 1985), but 3-5 oz./ton is closer to the norm. The silver-bearing species are uncertain. Samples of high grade silver ore were examined and found to contain a high proportion of galena suggesting argentiferous galena. However, assays as high as those reported above dictate the presence of a primary silver mineral such as argentite or native silver although none was observed in polished section.

Alteration consists of minor to extensive silicification, but in general silicification is far less prominent than in the heavily oxidized veins discussed below. Envelopes of weak propylitic alteration (calcite + chlorite + epidote) have been recognized adjacent to some veins, but the relationship is not universal and often can be seen only in thin section. The alteration is not the pervasive propylitic alteration that occurs in many of the western epithermal precious metal districts. Payne and Glass (1987) report hydrothermal alteration of amphibole to celadonite, but thin section analyses to date by the author have failed to confirm this observation.

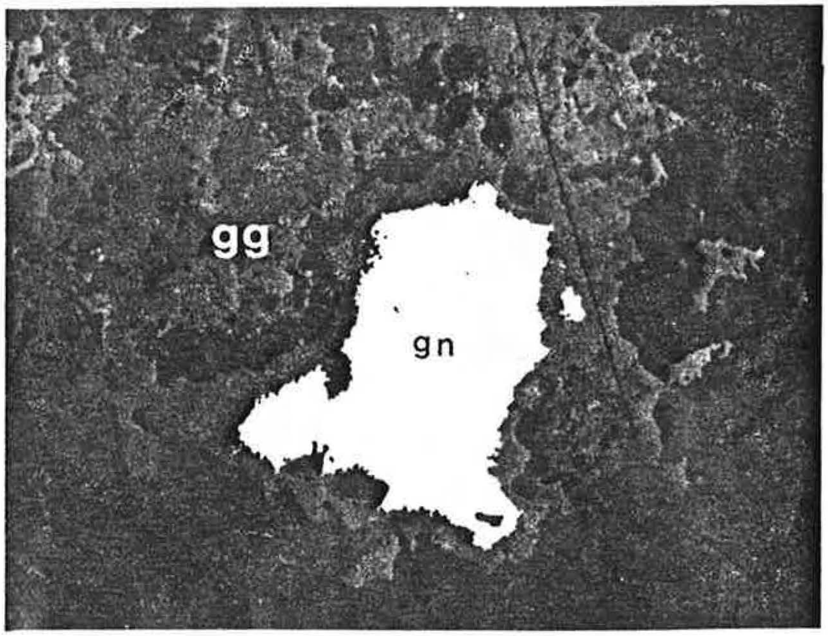


Fig. 6 Galena (gn) replacing gangue(gg) (100X)

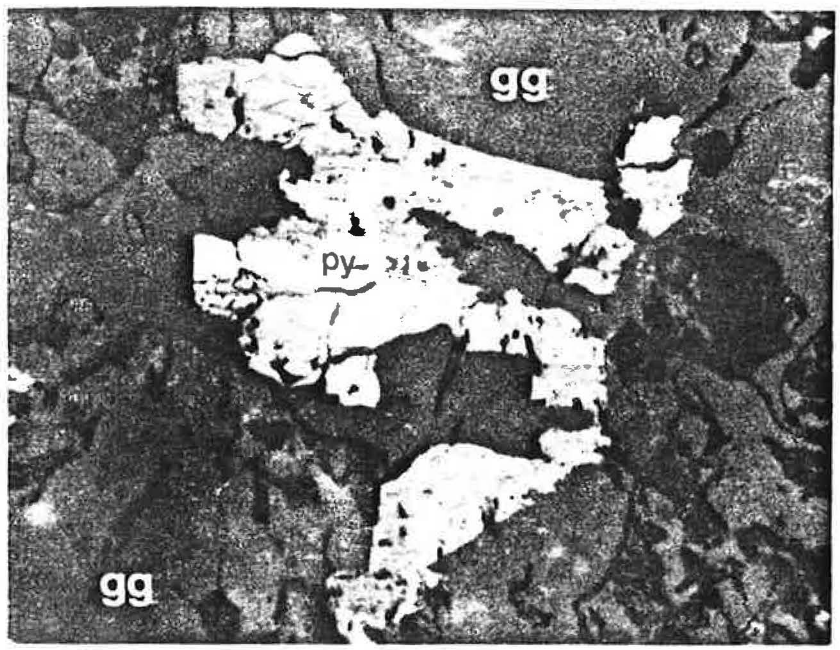


Fig.7 Pyrite (py) veined and replaced by hematite (100X)

Oxidized barite veins

Oxidized barite veins are thought to represent the oxidized equivalent of the black matrix barite veins. Although many of the black matrix barite veins show evidence of minor oxidation, few highly oxidized barite veins exist. They are easily recognized in the field by their brick red alteration adjacent to and intimately associated with the barite veins. The alteration consists of jasperoid and fine grained secondary hematite (Fig. 8). Most primary sulfides have been replaced with only occasional, heavily corroded, pyrite remaining. Galena has altered to cerrusite. Magnetite has been replace by hematite which now commonly appears as pseudomorphs of magnetite.

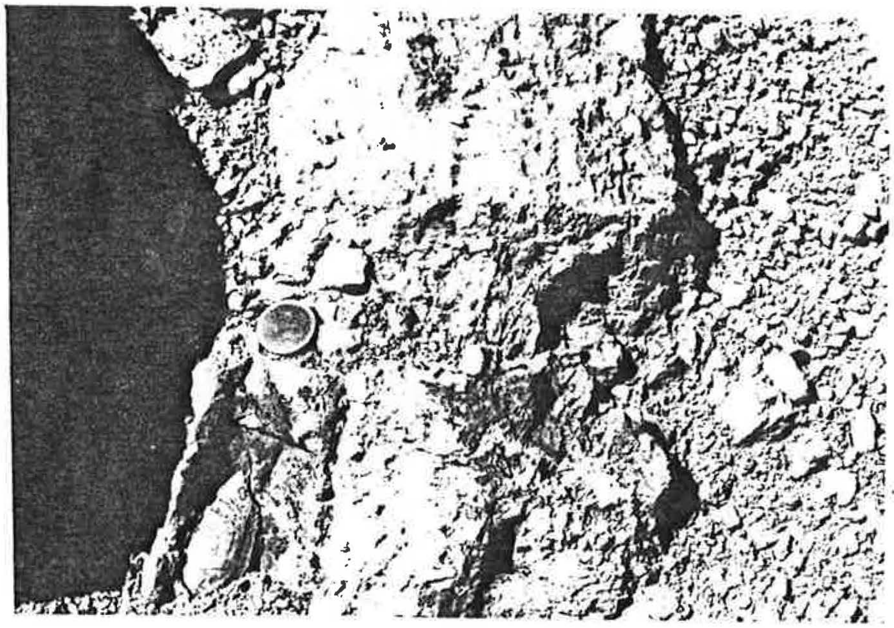


Fig.8 Oxidized barite vein (white)

Microscopically, fine grained to colloidal secondary hematite occurs as veins cutting the replaced and altered primary sulfides and oxides. Jasperoid consists of banded aggregates of iron-poor chalcedony and iron-rich jasperoid filling the interstices between barite fragments (Fig. 9). Secondary silver minerals, particularly embolite and cerargyrite are present in some samples but absent in most. Silver grades in Wall Street Canyon were reportedly quite high, generally exceeding 10oz./ton, but decrease dramatically to the west averaging 1-2 oz./ton in most of the unmined, oxidized veins. It is interesting to note that while oxidized barite veins are, in terms of shear numbers, vastly overshadowed by black matrix barite veins, they represent some of the larger veins in the district. At least one can be traced over 1000 meters along strike and in places exceeds 6 meters in thickness.

Fig. 9 Photomicrograph of barite (ba) partially replaced by colloform jasperoid/chalcedony (js) and quartz (Q). (50X)

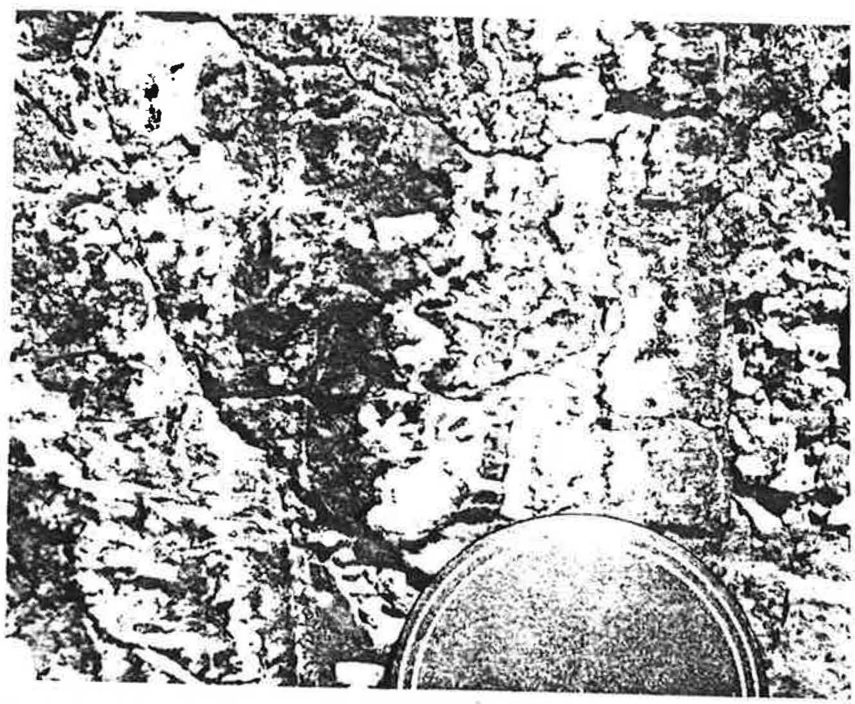


Fig. 10 Banded vein of barite (white) and jasperoid (gray).

The heavily altered and oxidized veins appear to cluster in distinct groups which generally lie adjacent to kinks or bends in the Calico fault. Their greater size suggests additional periods of dilation which may be related to extensional stresses built up near the bends in the Calico Fault. This subsequent dilation allowed the circulation of oxidizing meteoric waters.

Other vein types

A few unusual veins were noted during field studies of the district. In all cases these vein types are of restricted occurrence. Banded veins of jasperoid and barite occur near the St. Louis Mine (Fig. 10). They are unusual in their fine development of the "classic" comb structure often described as a signature of a true epithermal precious metal district. Interestingly, iron and manganese oxides are minor and sulfides absent. Late calcite veinlets sometimes crosscut the earlier barite and jasperoid.

Northeast of the Leviathan Mine (Fig. 1) monomineralic veins of snow white barite can be observed. Alteration is rare to absent. Inclusions of brecciated host rock can be seen at many localities. In contrast, southwest of the Leviathan Mine, thin but laterally persistent veins of jasperoid with no associated barite are present. The marked differences in mineral suites of these two vein types which lie within 300 meters of one another may be explained by their age relationships relative to mineralization. Monomineralic barite veins represent an early stage of mineralization while jasperoid

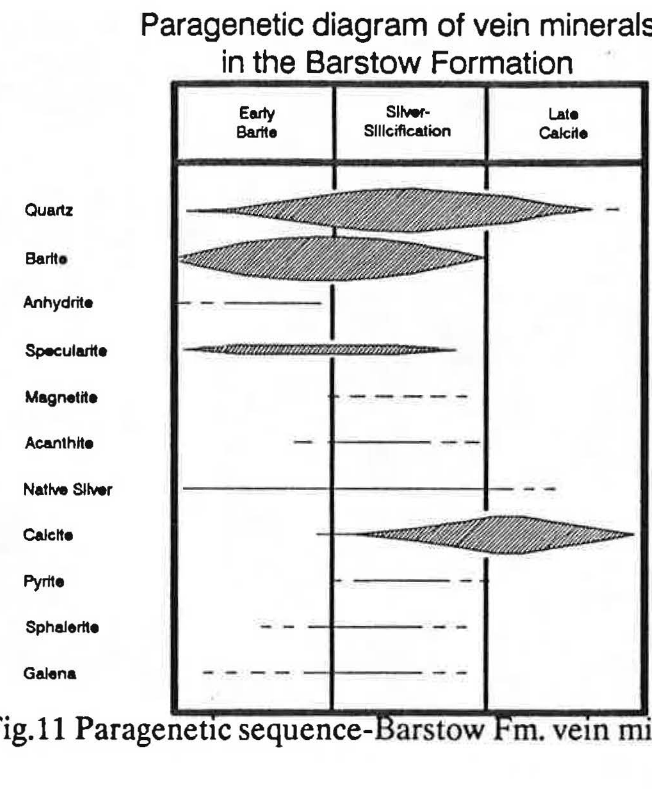


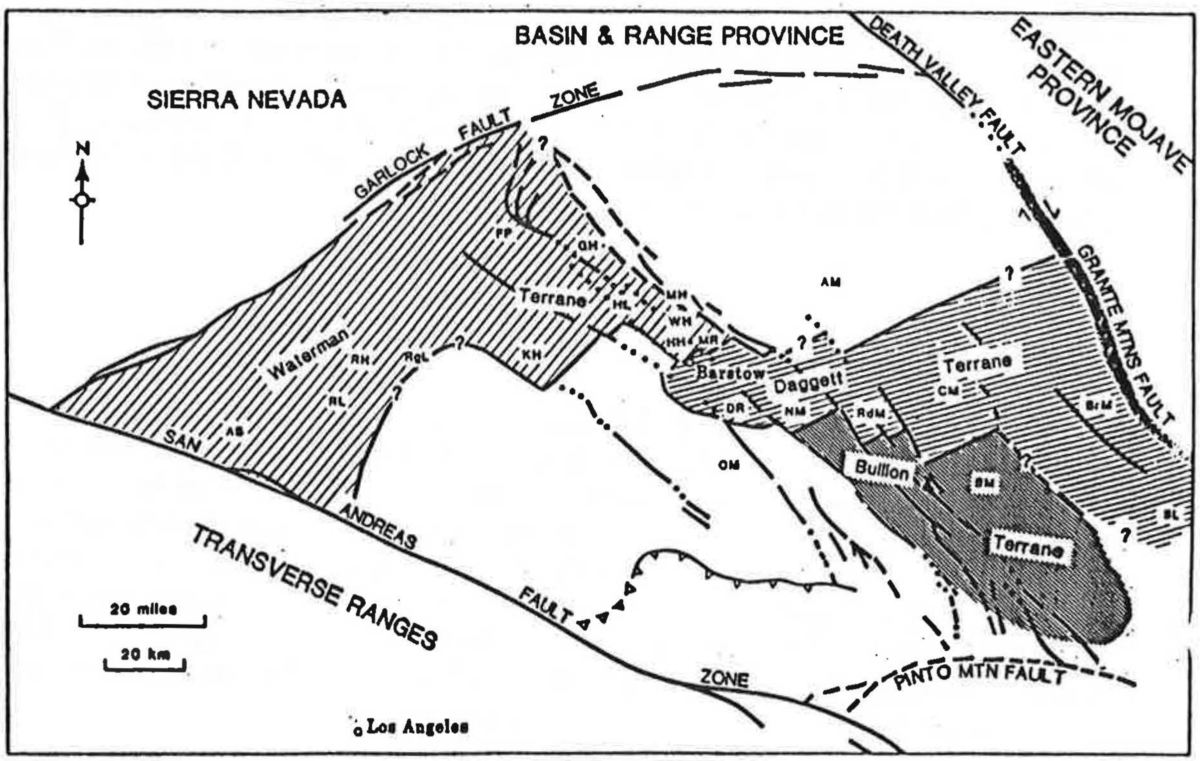
Fig.11 Paragenetic sequence-Barstow Fm. vein mineralization

veins represent the final stage of mineralization. The former vein type was sealed to the sulfides and oxides deposited after the barite, while the latter vein may not have dilated until meteoric waters were the dominant mineralizing fluids.

Barstow Formation Barite-Silver Mineralization

Mineralization within the Barstow Formation is largely of disseminated character. Fletcher (1986) reports that less than 1% of the primary barite-silver mineralization occurs in recognizable veins. Figure 11 is a generalized paragenetic diagram based largely on vein ores of the Waterloo deposit within the Barstow Formation.

Fletcher (1986) recognizes three stages of mineralization which correlate well with the paragenesis of the underlying Pickhandle barite-silver veins. The earliest stage, termed "Early Barite Veins", consists of barite and quartz with minor hematite and trace anhydrite and sulfides. The second stage, "Silver-Silicification Veins" are responsible for the bulk of the silver mineralization. These veins are composed primarily of quartz, lesser barite, minor hematite and calcite and trace sulfides and native silver. Acanthite and native silver have been identified as the chief ore minerals. The final mineralizing stage, "Late Calcite Veins" are predominantly coarse calcite and minor quartz.



Dokka,1988

Fig.12 Detached terrane in Mojave Desert (Dokka,1988)

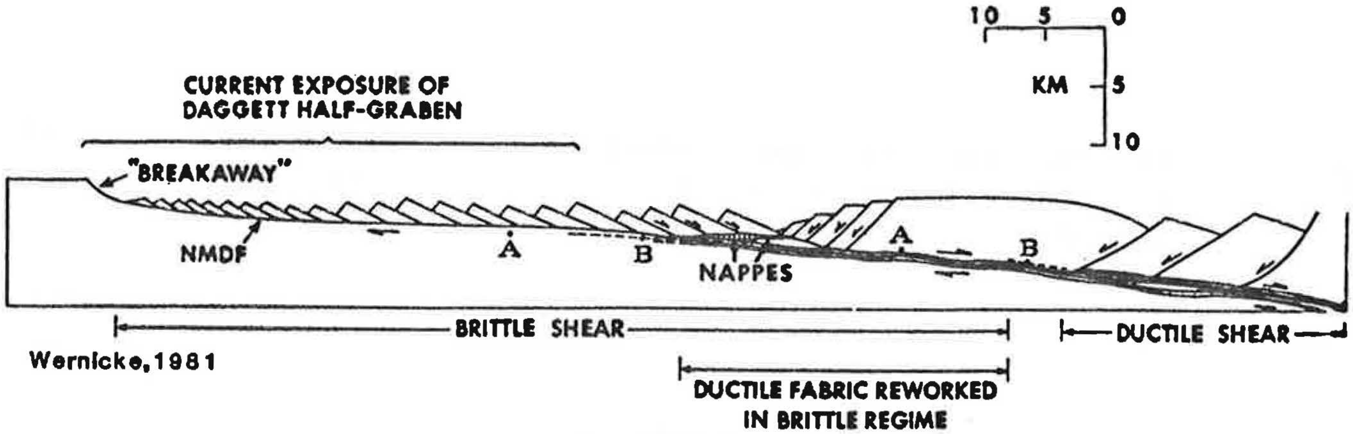


Figure 13

Alteration consists of early bleaching which most commonly manifests itself as K-feldspar replacement of detrital grains. Although not termed as such by Fletcher, this alteration in many respects appears similar to the pervasive potassic alteration associated with many base and precious metal mining districts. The alteration is correlative with the early stage of barite-quartz mineralization. Intense silicification accompanied the silver-silicification stage veins. It occurs most commonly as colloform bands of jasperoidal chalcedony although minor recrystallized quartz is also present. Fluid inclusion geothermometry, primarily from quartz, indicates temperatures of 175-185C and salinities of 4-6 wt %, typical of epithermal precious metal districts.

Controls for the Barstow mineralization are rather enigmatic. Studies of the sparse vein system (Fletcher, 1986) indicate a near random orientation typical of a stockwork vein system overlying an intrusive body. However, these vein orientations are inconsistent with those of the Pickhandle volcanics which strike dominantly northwest. Further there appears to be no genetic relationship between the ore deposit and the Calico Fault inasmuch as the Waterloo deposit has been offset by the fault. Finally, mineralization is pervasive throughout the lower portion of the Barstow Formation, apparently favoring no particular sedimentary horizon.

GROUND PREPARATION AND ORE GENESIS

Many have considered the Calico District to be a classic example of the epithermal precious metal deposit. Certainly the district has many features of the Lindgren type deposit: Tertiary age, association with volcanic rocks, mineralization in vein systems controlled by normal faults, low temperature mineralization and potassic and propylitic alteration. The most common epithermal model relates ore deposit emplacement to periods of arc and back-arc extensional volcanism associated with active plate subduction. The timing of mineralization in the Calico district, in the range of 14-17 MY, is inconsistent with the subduction-related model above in that an active convergent plate boundary to the west no longer existed during that interval.

Recent attention has been focussed on the detachment model to account for some of the structural controls present in many of the California desert precious metal districts. Low-angle faults were originally described along the flanks of the Calico Mountains by Weber (1976). These faults, however, bear little resemblance to the larger-scale detachment faults described by many workers in the Cordillera (e.g., Davis, 1980). The decoupled masses referred to by Weber in the Calico Mountains are surficial gravity slides, and may be only remotely related to the deep crustal extensional processes invoked in the discussion below. In addition, the Pickhandle ground preparation and the Barstow mineralization, whatever the cause, can be demonstrated to predate deformation associated with the "gravity slide" (Fletcher, 1986).

Detachment processes appear to have affected large areas in the Mojave (Fig. 12) and have resulted from regional extension. The transition in character of the plate boundary along the west edge of the North American Plate during the Tertiary undoubtedly played a primary role in the initiation of the extensional events. Involvement of major portions of total crustal thickness during extension is suggested by interpretations of seismic profiles where surface exposures of normal faults, interpreted to be detachments, can be traced on reflection profiles to mid-crustal levels.

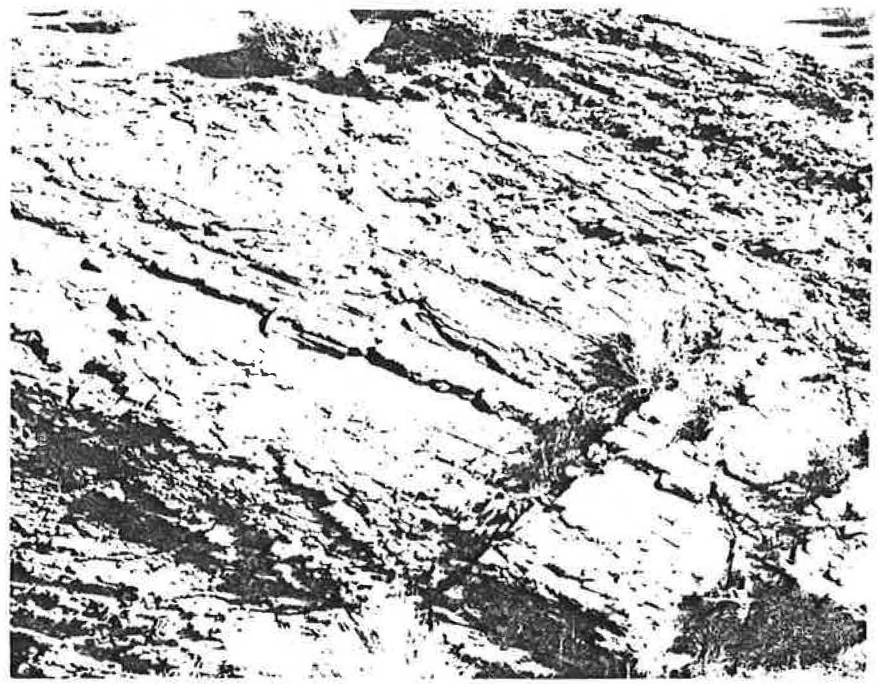


Fig.14 Detachment-related fault in Waterman Hills (hammer)

Extension is accomplished by ductile strain below depths in the 5 to 15 km range (Okaya and Thompson, 1986). In shallower regimes extension is accommodated through brittle mechanisms (Fig. 13) such as movement along decollements, high-angle normal faults which toe into the subjacent decollement and dike filling of extensional fractures formed in the upper plate (Wernicke, 1981).

Recently, Glazner and others (1988) and Dokka (1988) have described detachment faulting in the Waterman Hills and Mitchell Range a few kilometers to the west and southwest of the Calico Mountains. The Cordilleran metamorphic core complexes, described in detail elsewhere (e.g. Coney, 1980), have many similarities to the geologic features in the Waterman Hills and Mitchell Range. In those localities a metamorphic infrastructure, frequently mylonitic with chloritic alteration common along its upper margins, is separated from a carapace of younger faulted, extensionally fractured and dike filled allochthonous material. Figure 14 shows an example in the Waterman Hills of one of the faults in lower plate Waterman Gneiss. The southwest plunge of the fault striae probably reflects rotation along a younger fault related to the nearby Harper Lake strike-slip fault. Glazner and others and Dokka suggest northeast transport of upper plate rocks. Inasmuch as significant amounts of early Miocene (pre-Peach Springs tuff) clockwise rotation have been proposed, based upon evaluations of paleomagnetic data, by several workers (e.g. Ross and others, 1988), the actual translational paths were probably complex.

Investigations carried out more recently by the authors (e.g. Jessey and Marvin, 1988) in the Calico Mountains support the detachment model as a viable mechanism for ground preparation for subsequent mineralization. Utilizing the detachment model and assuming the Calico Mountains are within the upper plate of a detachment block, the mineralized, high angle, northwest striking faults are analogous to the normal faults observed commonly in detached terrane. Extensional stresses active during the early Miocene detachment faulting, opened up a series of dip-slip faults in the upper plate Pickhandle volcanics. Later, probably during middle Miocene, a small stock was emplaced in the vicinity of Wall Street Canyon which established a hydrothermal convective system mineralizing the dip-slip faults as well as the lower Barstow beds. Post-Barstow strike-slip movement began along the main Calico Fault reactivating the dip-slip faults. The reactivated faults underwent additional extension in areas adjacent to bends in the main Calico fault causing further dilation and permitting the circulation of meteoric waters which oxidized the existing mineralization and deposited secondary oxides and silver chlorides.

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GEOLOGY AND PRECIOUS METAL MINERALIZATION AT THE MORNING STAR DEPOSIT, SAN BERNARDINO COUNTY, CALIFORNIA.

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Abstract

Disseminated precious metal mineralization at the Morning Star gold deposit, San Bernardino County, CA, occurs in the hangingwall of the N20°W, 35°SW trending Morning Star thrust fault. Mineralization is hosted by the weakly peraluminous late Jurassic-early Cretaceous Ivanpah Granite, which is the earliest of six intrusive phases of the Teutonia Batholith. Pervasive propylitic alteration occurs in both the hangingwall and footwall Weak argillic± sericitic alteration occurs only in the mineralized hangingwall. Base and precious metal mineralization is associated with quartz±calcite, occurring both as cements in stockwork breccia zones and as veins subparallel to the fault.

Two stages of mineralization have been identified based on petrographic and electron microprobe analyses. An early stage of quartz, calcite, pyrite, hematite, chalcopyrite, galena, sphalerite, Ag-bearing tetrahedrite, and electrum is followed by a later stage of pyrite, covellite, digenite, hematite, acanthite, uytenbogaardtite (Ag_3AuS_2), native bismuth, and electrum. Electrum occurs as free grains and fracture fillings or as inclusions in pyrite during the early stage of mineralization, and as rims around early electrum or as intergrowths with covellite and acanthite in the later stage. Electron probe analyses indicate that early-formed electrum has an average fineness of 650, whereas all late-stage electrum has fineness greater than 820.

Fluid inclusions in quartz associated with the early stage of mineralization contain H_2O and liquid and vapor CO_2 at room temperature and have salinities of 6 wt.% NaCl eq. Microthermometric measurements (T_{mCO2}=-56.6±0.1°C) indicate that the gas phase is essentially pure CO_2 and, based on room temperature phase ratios, the inclusions contain 10-20 mole % CO_2. A minimum temperature of 280°C is estimated from the fluid inclusions.

Structural, mineralogical and fluid inclusion observations suggest that early Morning Star mineralization was structurally controlled and spatially and temporally associated with fluids of metamorphic affinity. Ore grades have subsequently been increased as a result of late stage hydrothermal processes.

Introduction

In recent years considerable advances in our understanding of the evolution of many major mesothermal gold deposits have been made by carefully relating such deposits to their structural setting within fault zones (e.g. Kerrich, 1986). Evolutionary models integrating episodes of faulting, fluid pressure cycling and precipitation of ore minerals within dilatant fractures have been proposed (e.g. Sibson, 1987; Sibson et al., 1988) to explain observed relationships between ore deposits and structural evolution. Examples include the mineralized shear zones at Yellowknife, Northwest Territories, Canada (Kerrick and Allison, 1978) and mineralized detachment faults such as Picacho, California, (Drobeck et al., 1986), but little attention has been paid to mineralized thrust

faults. The Morning Star deposit clearly constitutes one such natural example of a mineralized thrust fault. This paper presents data on the geology, mineralogy, and geochemistry of the Morning Star deposit in an attempt to unravel the relationship between structural setting and mineralization.

Location and Mining History

The Morning Star precious metal deposit is located on the eastern flank of the Ivanpah Mountains near the eastern edge of the Mojave Desert, California, approximately 100 km southwest of Las Vegas, Nevada, and 350 km northeast of Los Angeles, California (Figure 1). The mine is situated at an elevation of roughly 1420 meters above sea level.

Gold mineralization was discovered in the area of the Morning Star deposit in 1907. The property was prospected intermittently until the late 1930's when it was acquired by Haliburton Oil Company. Haliburton performed extensive underground exploration which blocked out 2 million tons of gold ore. In 1942 the operation was shut down prior to the onset of gold production due to the war effort. Vanderbilt Gold Corporation, the current owner and operator of the property, acquired the Morning Star in the 1960's and reopened the existing workings and underground exploration. From 1980 to 1982 the mine was developed as an underground operation utilizing trackless mining techniques. In 1986 the mine was converted to an open pit cyanide heap-leach operation and full scale production of crushed ore began in late 1987. Proven reserves are approximately 8 million tons of ore at 0.06 ounces of gold per ton and the mine life is projected at 9 to 10 years with a 40 to 55 thousand ounces of gold per year production schedule (Ausburn, 1988).

Tectonic and Geologic Setting

The Ivanpah Mountains are situated at the southern extreme of the relatively continuous Mesozoic Sevier thrust belt (Burchfiel and Davis, 1972;1975;1988) within the Jurassic magmatic arc as defined by Kistler (1974). Thrusting in the Ivanpah and Clark Mountains involves Precambrian crystalline basement, whereas thrusting north of the Clark Mountains is stratigraphically controlled (Burchfiel and Davis, 1972;1975;1988). Stacked thrust sheets of cratonic Precambrian and Paleozoic sedimentary rocks and Precambrian crystalline basement define the Clark Mountains, the northern-most Ivanpah Mountains (Burchfiel and Davis, 1971), and the New York Mountains (Burchfiel and Davis, 1977). At least two periods of thrusting have been established for the Clark and northern Ivanpah Mountains by Burchfiel and Davis (1971); an earlier period prior to 190 Ma and at least one additional period between 138 and 85 Ma. Pre-thrusting normal faults (e.g. the Kokoweef Fault, Figure 1) expose a large section of Precambrian crystalline basement in the northern-most Ivanpah Mountains. Other mountain ranges in the eastern Mojave Desert have been cut by post thrusting Tertiary extensional faulting, some of which caused normal fault movement on older thrust faults (Burchfiel and Davis, 1988), but no evidence of extensional

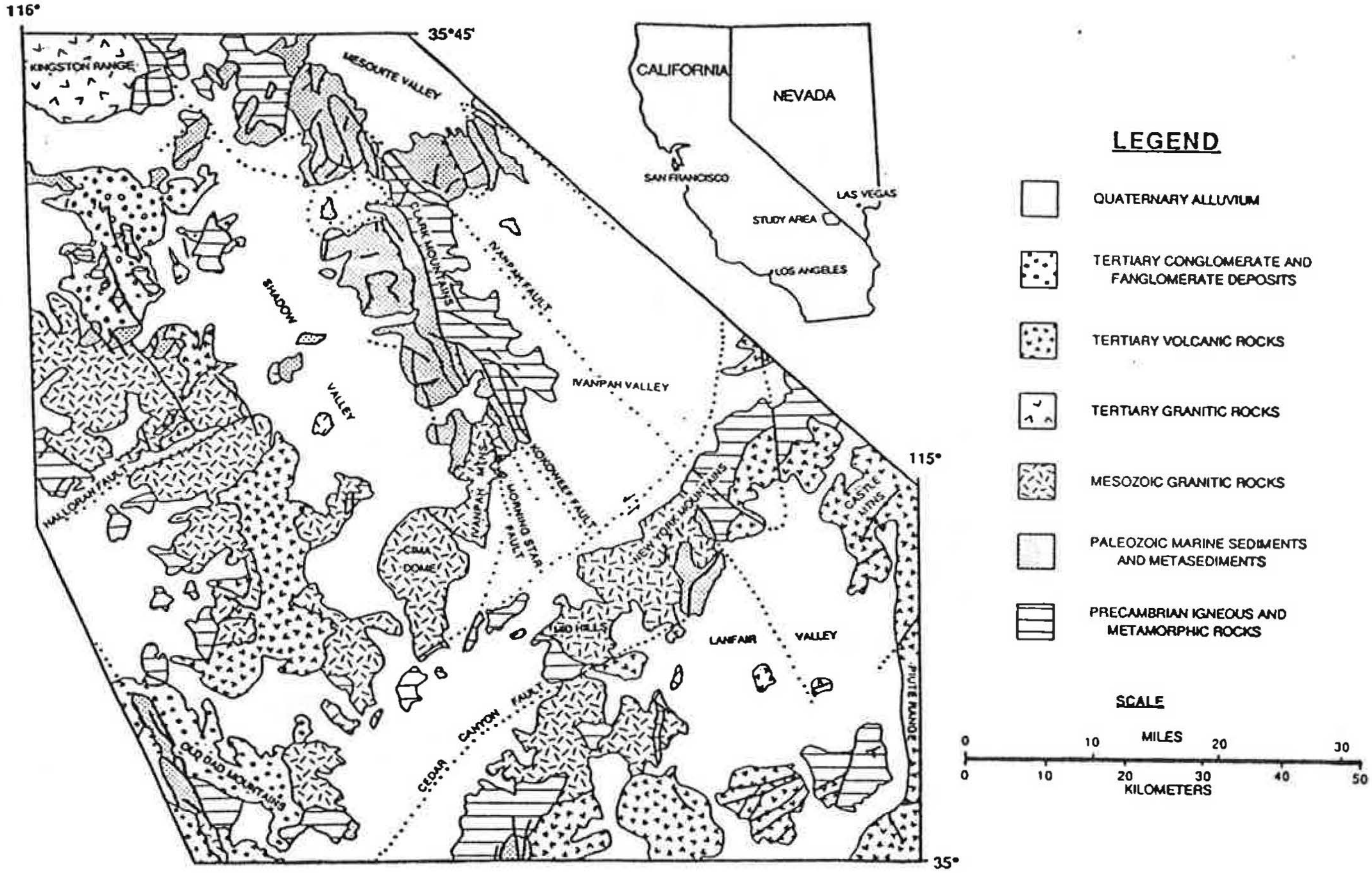


FIG. 1 Location map and generalized geologic map of the eastern Mojave Desert. The location of the Morning Star deposit is shown by the black square on the eastern side of the Ivanpah Mountains. Map based on Jennings (1977).

tectonism exists in the Ivanpah Mountains. Cenozoic strike-slip faulting (e.g. fault in the Ivanpah Valley, Figure 1) acted to accommodate differential movement between the small tectonically emplaced blocks.

The Morning Star deposit is hosted by the Ivanpah Granite adjacent to the Morning Star fault (Figure 1). The Ivanpah Granite is the oldest of six distinct igneous intrusions that constitute the Mesozoic Teutonia Batholith - the largest igneous complex in the eastern Mojave Desert (Beckerman et al., 1982). The Ivanpah Granite is a marginally metaluminous course-grained biotite granite (Weisenberg, 1973; Beckerman et al., 1982) that intruded into folded Lower Grand Canyon Series Paleozoic sedimentary rocks as a "sheet-like" pluton (Burchfiel and Davis, 1971). A minimum K/Ar age of 138 Ma has been determined for the Ivanpah Granite (Sutter, 1968); subsequent workers have suggested the granite may belong to a 158 to 132 Ma magmatic epoch (Robinson, 1979). Burchfiel and Davis (1971) distinguish a more mafic plutonic rock at the contact between the Ivanpah Granite and the Paleozoic carbonates on the western edge of the Ivanpah Mountains. Weisenberg (1973) believes that this phase constitutes a mafic differentiate produced when the

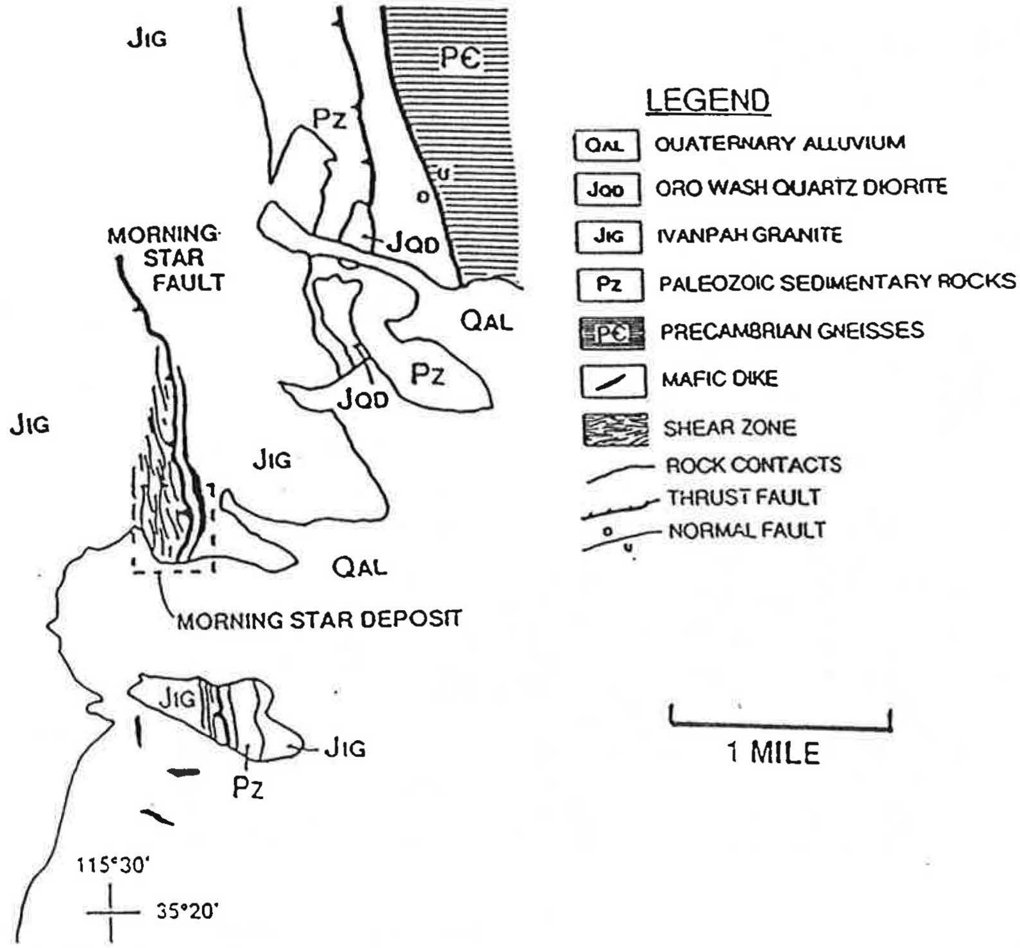


FIG. 2 Generalized geologic map of the eastern Ivanpah Mountains showing the Morning Star deposit. A schematic cross section of the deposit from the NE to the SW is shown in Figure 3.

Ivanpah Granite reacted with the intruded carbonate sequence. An approximate age of 167 Ma has been established for this mafic contact zone (Sutter, 1968), thus establishing a minimum age for the Ivanpah Granite of 167 Ma. Later igneous activity in the Teutonia Batholith took place between 110 and 75 Ma (Burchfiel and Davis, 1977; Beckerman et al., 1982).

Geology and Structure within the Deposit

Rocks in the vicinity of the Morning Star deposit are dominated by the medium to course grained Ivanpah Granite which is composed of approximately 60% K-feldspar, 20% quartz, 15% plagioclase feldspar, and 5% biotite and has a slight magmatic fabric consisting of aligned biotite (Weisenberg, 1973). Beckerman et al. (1982) and Weisenberg (1973) provide a more detailed description of the Ivanpah Granite. Coarse grained pegmatitic and fine grained aplitic dikes and sills are common; these are interpreted as late stage differentiates of the Ivanpah Granite. Small

intrusions of porphyritic granite also cut the Ivanpah Granite. Field observations suggest the porphyritic intrusions are similar in appearance and mineral composition to later intrusions within the Teutonia Batholith.

The area surrounding the deposit is also cut by numerous fine to medium grained mafic dikes of diabasic to dioritic and lamprophyric compositions. A large pre-tectonic mafic dike outcrops in the footwall below the Morning Star fault within the deposit, but is absent, or at least has not been recognized, along the continuation of the fault to the south of the deposit (Figures 2 and 3). Minor mafic dikes of various orientations do, however, occur throughout the area south of the deposit. The dikes may be important for constraining the relative ages of deformation and mineralization in and around the deposit, but the origin and timing for most of the mafic dikes has not been established to date.

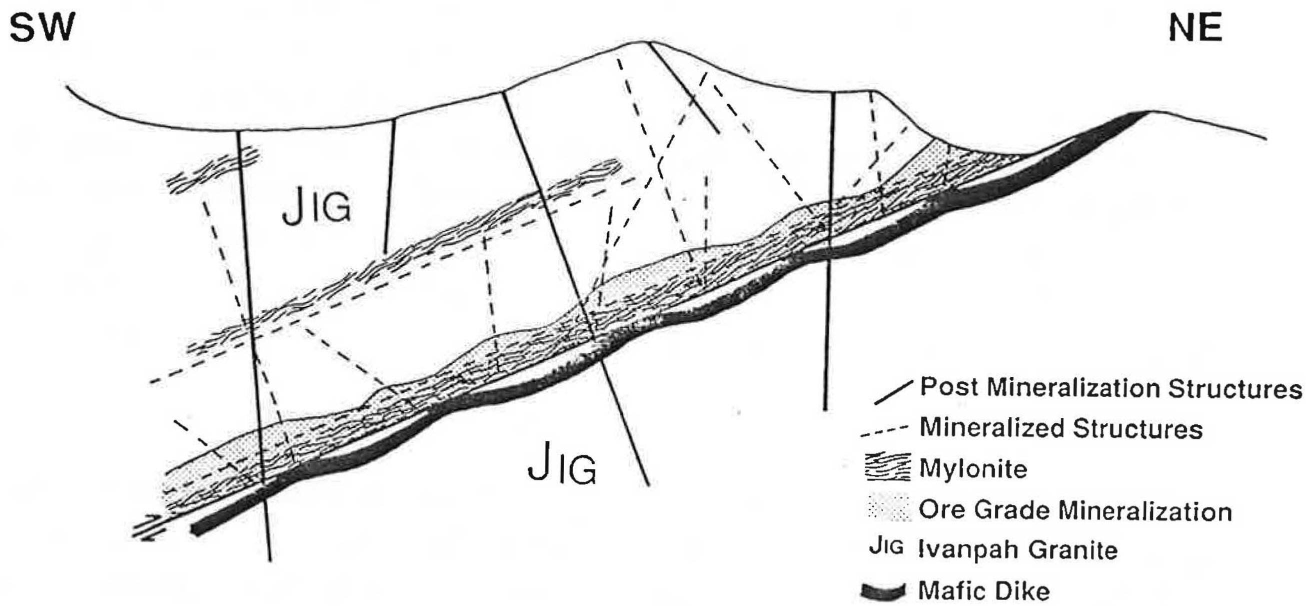


FIG. 3 Schematic cross section across the Morning Star mine. Figure modified after Ausburn (1988).

Precious metal mineralization is confined to the hanging wall of the low angle Morning Star fault which trends roughly N20°W, 35°SW. The fault outcrops in the Morning Star mine as a 0.3 - 1.0 m thick fault gouge zone. The fault gouge consists of variable-sized bleached granite fragments surrounded by anastomosing clay selvages exibiting multiple orientations of slickensides. Gouge in the fault is typically well-foliated and the lower boundary between the fault zone and the host granite is sharp. The amount of displacement on the fault is unknown at the present time. In the hangingwall sub-planer mylonite zones are developed within the granite and dip sub-parallel to the fault (Figure 3); no such zones of crystal-plastic deformation have been observed in the footwall. The lower contact between each mylonite zone and undeformed granite is sharp, but the

upper contact grades into a foliated granite, the foliation weakening away from the mylonite. Weak dip-parallel mineral lineations are observed on some mylonites. A 0.3 m thick breccia zone, commonly containing angular clasts of mylonitic rock, is found at the hangingwall-fault contact within the mine. The zone of cataclastic and mylonitic deformation is approximately 500 m wide in the vicinity of the mine.

Faults and fractures of various orientations cut the hangingwall, and to a lesser extent, the footwall rocks (Figure 3). Two sets of mineralized structures, confined to the hangingwall, have been identified. One set strikes N to NW and dips vary from (1) sub-parallel to the Morning Star fault, (2) moderately dipping in the same direction as the Morning Star fault - some of these structures asymptotically approach the fault at depth -, and (3) dipping back at a high angle into the Morning Star fault (Figure 3). The second set vary in strike from NE to E-W and dip at a high to moderate angle. Mineralized veins occupy these dilatant zones and are described below. Structures that cut both the hangingwall and footwall contain clay-chlorite fault gouge and slickensides, and are consistently unmineralized. The post-mineralization structures roughly trend E-W, at a high angle to the Morning Star fault, and always have a steep dip (from 60°N to 60°S).

Pervasive propylitic alteration, characterized by chlorite±epidote±pyrite±calcite, occurs in both the hangingwall and footwall. A weak to moderate argillic±sericitic alteration occurs only in the hangingwall, especially along and at the intersections of the mineralized structures. Silicification, defined as discrete veins, veinlets, and stringers of quartz, also occurs throughout the hangingwall. Silicification rises to a much higher structural level than ore mineralization.

Mineralization

Mineralization occurs as disseminated pockets of sulfide minerals and electrum in the series of syn- to post-tectonic quartz±carbonate stockwork breccia zones and veins of variable orientation in the hangingwall of the Morning Star fault. Vein textures, such as euhedral, growth-zoned quartz crystals, indicate vein formation by open fracture filling. Ore grade mineralization occurs along the fault and within and at the intersections of the breccia zones and veins (Figure 3). No mineralization has been found in the mylonite that parallels the fault within the ore zone, except where the mylonite is cut by later veins or brecciated, indicating that mineralization postdates mylonitization. Localized pockets of mineralization, not large enough to constitute ore, are confined to quartz±carbonate veins at higher structural levels of the hangingwall. Fire assay of exploration drill core detects only traces of gold in the gouge zone and no mineralization occurs below the fault zone.

Ore petrography and electron microprobe analyses have identified two stages of mineralization, designated primary and secondary, that were deposited under differing physical and chemical conditions (Sheets et al., 1988). Primary mineralization consists of early quartz, pyrite,

sericite, hematite and ilmenite, followed by carbonates and galena and electrum, and finally by chalcopyrite, sphalerite, and silver-bearing tetrahedrite (Figure 4). Electrum was deposited during the primary stage of mineralization as free grains in quartz and as inclusions and fracture fillings in pyrite. Primary electrum in pyrite commonly coexists with galena. Electrum deposited during the primary stage of mineralization has a lower fineness than electrum deposited during the secondary stage as described below. Quartz was deposited during the entire primary stage of mineralization, and carbonates occur in all except the earliest portions of the primary stage. Pyrite is the only Fe-sulfide mineral present in the deposit.

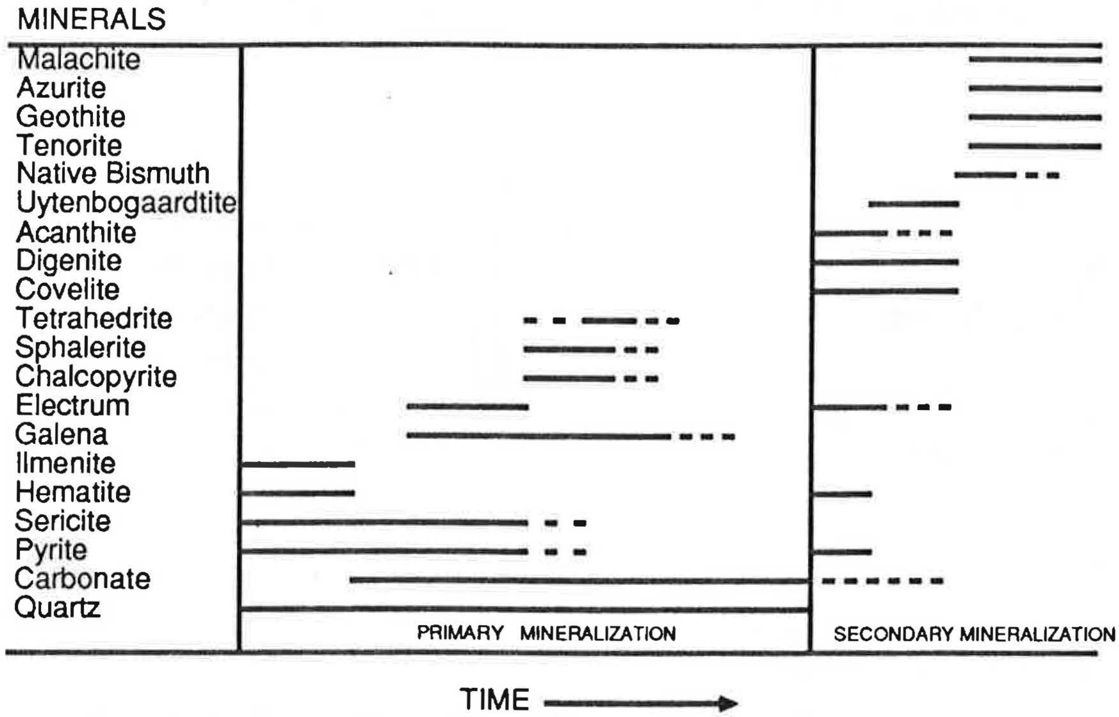


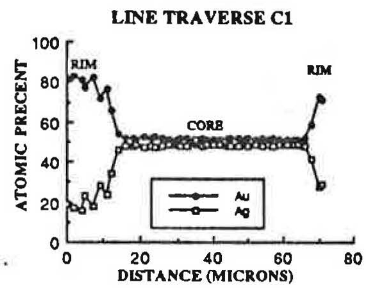
FIG. 4 Generalized paragenetic sequence for the Morning Star deposit.

Secondary mineralization consists of minor pyrite and hematite, occurring as overgrowths on original grains, and carbonates. Covellite, digenite, acanthite, uytenbogaardtite (Ag_3AuS_2) and electrum also occur during the early part of the secondary mineralization. Covellite occurs in zones containing precious-metal mineralization, while covellite and digenite coexist in veins containing only base-metal sulfides. The remaining minerals in the secondary episode are clearly supergene and may constitute a tertiary episode of mineralization.

During the secondary stage of mineralization, electrum occurs (1) intergrown with acanthite and/or uytenbogaardtite containing inclusions of covellite and (2) as rims around primary electrum grains. The composition of uytenbogaardtite from the Morning Star deposit appears to be enriched in sulfur and depleted in gold relative to the original analyses of Barton et al. (1978). Three to five

wt.% Cu occurs in uytenbogaardtite from the Morning Star deposit and may be responsible for the apparent gold depletion and sulfur enrichment.

Primary electrum spatially associated with secondary mineralization is commonly rimmed by electrum having a more golden color. Detailed electron microprobe analysis of these electrum grains reveals gold-rich rims surrounding a core grain containing a lower gold content. The gold-rich rims are readily outlined by microprobe traverses across the grains (Figure 5). The difference in electrum fineness between the two stages of mineralization is distinct when plotted as a histogram of the average fineness for individual grains, cores, and rims (Figure 6). Electrum deposited during the primary stage of mineralization is restricted to fineness between 630 and 690, while electrum deposited during the secondary stage of mineralization has a fineness greater than 820.



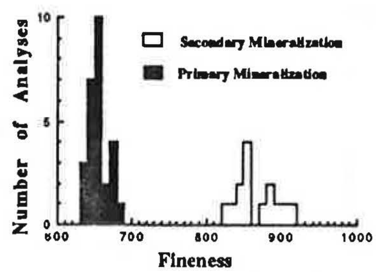


FIG. 5 **FIG. 6**

FIG. 5 Representative microprobe traverse across an electrum grain showing the higher gold content in the rims than in the core.

FIG. 6 Fineness histogram for electrum analyses at the Morning Star deposit. Each analysis represents the average fineness for that particular grain, core, or rim.

Fluid Inclusions

Pockets of primary mineralization are surrounded by euhedral quartz crystals that exhibit a crude growth zoning. The crystals usually contain a milky white core with abundant fluid inclusions and an outer, relatively clear, growth zone containing embayments and inclusions of primary stage sulfide minerals and fluid inclusions. Fluid inclusions described in this paper surround pockets of chalcopyrite±pyrite±galena, but no electrum was found in these pockets. The mineral paragenesis suggests these fluids are associated with late stage or post-electrum deposition. No microthermometric data has been obtained from fluid inclusions within the cores of quartz crystals because of their extremely small size (generally >5 microns) and the inability to distinguish primary, psuedosecondary, and secondary inclusions.

Primary fluid inclusions within the outer growth zone contain liquid H_2O and liquid and vapor CO_2 at room temperature. Based on room temperature phase ratios, the inclusions contain 10-20 mole % CO_2. Melting temperatures of the CO_2 phase of -56.9 to -56.6°C indicate that the CO_2 is essentially pure. The CO_2 phases homogenize to the liquid phase at 30.3 to 30.8°C, and total homogenization occurs at 281.3 to 305.4°C. Clathrate melt in the presence of liquid and vapor CO_2 at a temperature of 6.6 to 7.1°C corresponds to 5.6 to 6.5 wt. % NaCl eq. according to the equation of Bozzo et al. (1975). No independent geothermobarometer is available at the present time, thus no pressure correction can be applied to the homogenization temperatures. Therefore, a minimum temperature of primary mineralization is 280°C. The observed composition and behavior of fluid inclusions is similar to that of inclusions from medium to high grade metamorphic rocks and suggests a metamorphic affinity for fluids associated with primary mineralization.

Discussion

STRUCTURE

Field evidence indicates that the Morning Star fault is an eastward directed thrust fault as originally mapped by Burchfiel and Davis (1971). The following three lines of evidence substantiate this interpretation. First, it is consistent with the regional tectonics of the Clark, northern-most Ivanpah, and New York Mountains as outline previously. The Morning Star fault also has an orientation consistent with regional thrust faulting in the eastern Mojave Desert and may represent the development of Mesozoic thrusting following the initial emplacement of the Teutonia Batholith. Second, crystal-plastic deformation is only observed in the upper plate of the Morning Star thrust. This geometry is indicative of deeper crustal level deformation thrust over shallow level brittle deformation. Normal movement could not account for such a juxtaposed sequence and strike-slip faulting would require a substantial thrust component to produce such a sequence. Last, the dip-parallel mineral lineations on the mylonites suggest normal or thrust type movement and, as outline above, normal (extensional) movement is not likely.

Mylonites may have developed along the magmatic foliation within the Ivanpah Granite. This could account for multiple planes of shearing as seen in the Morning Star mine (Figure 3). In the transition from ductile to brittle deformation considerable cataclasis and fracturing is likely to occur. The thick fault gouge developed on the thrust plane and dilatant zones that now host the mineralization are examples of this deformation. Evidence for this also includes the quartz and calcite cemented brecciated mylonite directly above the Morning Star thrust. Veins parallel to the basal thrust adjacent to mylonite zones and anastomosing into the basal thrust may represent brittle minor thrust movements that enhanced the porosity and caused channelways for mineralizing fluids. The high angle, unmineralized E-W structures clearly post-date thrusting as they cut the basal thrust; the origin of these structures is not well understood at the present time.

MINERALIZATION

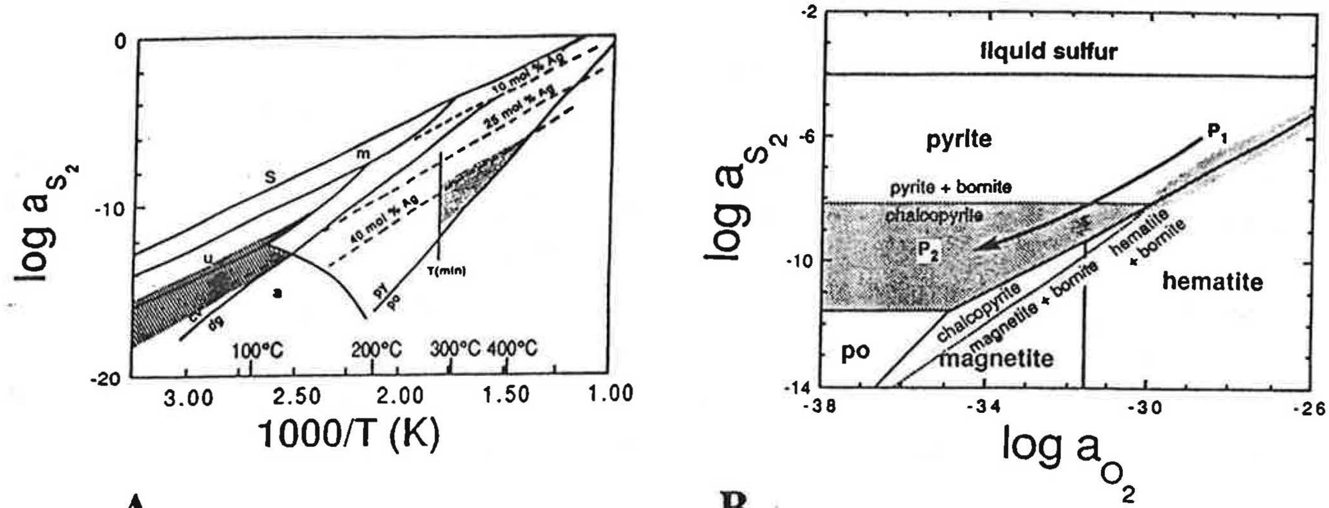
Using preliminary fluid inclusion temperature, mineral occurrences, and the fineness of electrum, it is possible to place some constraints on the environment of deposition for the two stages of mineralization (Figure 7). In Figure 7A primary stage mineralization is constrained to be (1) equal to or greater than the minimum temperature of inclusion formation (280°C), (2) on the pyrite side of the pyrite-pyrrhotite equilibrium curve and (3) between the curves for 38 and 55 mole percent silver in electrum (corresponding to a fineness of 630 and 690, respectively), as indicated by microprobe analyses. Secondary mineralization is constrained to the uytenbogaardtite field below the curve for 18 mole percent silver in electrum (fineness = 920) and in the acanthite field above the curve for 27 mole percent silver in electrum (fineness = 820). Thus deposition of primary stage mineralization took place between a sulfur activity of 10^{-6} and 10^{-11}, while secondary stage mineralization took place in the range $10^{-10.5}$ and 10^{-19}. A maximum temperature of formation for the secondary stage of mineralization is thus established to be 135°C, but no minimum temperature is available at the present time.

The coexistence of early pyrite and hematite places some constraints on the activity of oxygen during the primary stage of mineralization (Figure 7B). Early in the primary stage the activity of S_2 and O_2 are constrained to be along the pyrite-hematite equilibrium curve, but later, during chalcopyrite deposition, the activity of S_2 and O_2 decreases, moving into the pyrite field on the chalcopyrite side of the pyrite+bornite=chalcopyrite curve. No absolute numbers are given because of the poor constraints on the temperatures throughout the primary stage of mineralization.

Thus, the two episodes of mineralization occurred under distinctly different conditions, but details of the spatial and temporal relations have yet to be well constrained. Mineralization occurred initially at a relatively higher activity of S_2 and O_2, and base metal mineralization precipitated at a relatively lower activity of S_2 and O_2. The mechanism for gold transportation and deposition are not adequately understood at the present time, but some inferences can be made from the activity of S_2 and O_2. For example, the general solubility reaction for gold can be written

$$Au + (x/4)O_{2(g)} + xH^{+} + mL^{-n} = AuL_{m}^{+(x-mn)} + (x/2)H_2O \qquad \text{(I)}$$

where x depends on the gold oxidation state ($Au_{(I)}$ or $Au_{(III)}$) and L^{-n} is the complexing agent. At a constant pressure, temperature, and pH, as the oxygen activity drops any gold complex will become less stable relative to free gold so deposition will occur. Electrum deposition occurs between the assemblege hematite+pyrite and the deposition of base-metal sulfides, so the lowering of the O_2 activity may be a mechanism for deposition.



A. **B.**

FIG. 7 A. Activity of S_2 verses temperature diagram for mineralization at the Morning Star Deposit. **S** = sulfur condensation curve; **m** = low-temperature AgAuS; **u** = uytenbogaardtite; **a** = acanthite; **cv** = covellite; **dg** = digenite; **py** = pyrite; and **po** = pyrrhotite. T(min.) is the minimum temperature of formation for the primary stage mineralization as defined by fluid inclusions (280°C). The dashed lines are isopleths of mole percent silver in electrum. Primary stage mineralization is shown in the dotted pattern and secondary mineralization is shown in the lined pattern.

B. Activity of S_2 verses activity of O_2 diagram for primary stage mineralization at the Morning Star deposit. Diagram constructed for 280°C. **po** = pyrrhotite. Primary stage mineralization is shown as the dotted pattern, where P1 represents early and P2 represents later primary stage conditions. Sources of data, for both diagrams, are Barton and Skinner (1979), Barton (1980), and Barton (1984).

FLUIDS

The origin and timing of fluid migration is not well constrained at the present time. Syn-tectonic fluids may have migrated up the thrust fault via a seismic pumping mechanism (e.g. Sibson, 1987; Sibson et al., 1988) or post-tectonic fluids may have migrated into dilatant zones to deposit the mineralization. Fluid inclusions associated with the primary mineralization clearly indicate fluid evolution at depth, possible from a metamorphic source. The structurally controlled mineralization and alteration suggest the fault plane and upper plate structures acted as major channelways for fluid migration. Development of a thick fault gouge during thrusting would have restricted fluid flow to the hangingwall and prevented mineralization in the footwall rocks. Other fluids may have mixed with the high temperature primary fluids to form the secondary stage of mineralization, causing a second episode of electrum deposition that has enhanced the ore grades at the Morning Star deposit. The secondary episode of mineralization is believed to be due to low temperature hydrothermal process, instead of supergene processes, because of the existance of the early pyrite+hematite mineral assemblege. The type of fluids associated with secondary mineralization is not known at the present time.

Conclusions

Precious metal mineralization at the Morning Star deposit occurs in the hangingwall of the

eastward directed Morning Star thrust fault, which may represent a Sevier age thrusting episode within the Teutonia Batholith. Two distinct episodes of mineralization, both containing electrum, have taken place. The primary episode of mineralization occured at a minimum temperature of 280°C as established by CO_2-H_2O-NaCl-bearing fluid inclusions. Early primary stage mineralization occured at a higher activity of S_2 and O_2 than later primary stage mineralization, and secondary stage mineralization occured at evan lower S_2 activities. Changes in the activity of O_2 may account for primary stage electrum deposition, but more constraints are required for the secondary stage. The ore grade of the deposit has been enhanced by the deposition of secondary electrum, especially where it occurs around primary electrum grains.

Acknowledgments

The authors would like to thank John Jordan, Jr. the president of Vanderbilt Gold Corporation for financial support and for access to the Morning Star mine. Helpful reviews by M. N. Nyman are greatly appreciated.

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MINERAL POTENTIAL, TIME AND ECONOMIC PERMISSIVENESS

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ABSTRACT

The southern California desert has a heritage of mineral exploration and mining. This heritage is as important now as it was in the past. Today, at least 25 mineral commodities valued at $1.3 billion annually reflect this economic benefit. Additional indirect and induced benefits are estimated to create a total real worth of $2.2 billion.

The CDCA (California Desert Conservation Area) of southern California contains 25 million acres of which 9.7 million acres are public lands available for mineral development. Currently proposed legislation (S11) would create 8.8 million acres of wilderness and reduce the public land available for mining to 4.1 million acres. This protectionist movement claims that current mining would not be affected, and that these areas have no future mineral potential, and that California does not require additional mineral reserves.

In reality, however, such a removal of public lands will diminish mining and will almost immediately kill mineral development in California. The rocky and mountainous areas emphasized for wilderness are the very areas with exploration potential. Such abject pessimism regarding mineral potential denounces our free enterprise system protected by the Mining Law of 1872. One need only look to recent economic changes which have revitalized California's annual gold production up to $60 million in 1985 and to 270 million in 1987.

The Mesquite mine discovery announced by Gold Fields Mining Corporation in 1982 is one example of totally unexpected mineral wealth, which currently has an estimated annual production value of $72 million. The mine, in Imperial County, employs 260 people with an annual payroll of $8 million. It is responsible for a total of 700 mining equivalent jobs with an effective payroll of $22 million. To refute similar such economic opportunities is totally unacceptable.

HISTORICAL INTRODUCTION

The California gold rush of 1849 provided the catalyst needed to accelerate California's pioneer development and general growth. During the next 10 years, gold was extracted from the surface at a rate of over 2 million ounces per year from the placers along the Mother Lode country of northern California. This rate of production gradually diminished, and from the years 1865 to 1942 production ranged from over 500,000 ounces to one million ounces per year. California justifiably received world prominence as the golden state. Following 1942, world conditions virtually brought California gold mining to a halt. The World War II order L208 of 1942 closed most of the California gold mines. Post war reconstruction was accompanied by continuous inflation. Such an economic environment could not support a gold industry on a price of gold fixed at $35 an ounce. Subsequently, gold production in California was reduced to a scarcely measurable amount during the years from 1968 to 1982. Most of the California gold ounces during this period were derived from a few faltering but persistent dredge operations in northern California. A vestige of the gold mining districts was preserved by virtue of the Mining Law of 1872, which protected the vanishing breed of people we call prospectors. These tenacious individuals clung to their hopes and eked a living from their mining claims. The potential for gold in California was awakened in 1985, when statisticians revealed an annual gold production valued at $60 million. By the end of 1987 gold production was reported at $270 million. Time had run its cycle and the decontrol of gold prices was beginning to have repercussions. On March 15, 1968 the U.S. Treasury allowed gold to trade on the free market. The price of gold did not begin to climb until 1972, but by 1978 a $200 per ounce price was broken. This economic permissiveness now made gold interesting. The price was right. But mining permissiveness in California, as well as other parts of the nation

had changed dramatically. The 35 years, and particularly 10 years, prior to 1978, had altered mining potential in California significantly. This occurred not from the lack of resource availability, nor the lack of demand but from the access to exploration and development. The population explosion along the west coast and sprawling suburban development began to affect mine development generally and the potential for gold production in much of the Mother Lode country.

MINERAL AND SOCIAL EVOLUTION

Nevertheless, for local demands, the growth of non-fuel mineral production in California tried to keep pace with the population, in addition to the general economic growth of California by meeting certain global demands. California's nonfuel mineral production led all other states in 1987 with an estimated value of $2.5 billion (Burnett, J.L. 1987). Construction minerals, including cement, sand and gravel and crushed stone, supplied the main demand with a value of $1.3 billion or over 50 percent. The remaining 50 percent of California minerals provided export opportunities and created a positive economic balance. This positive balance includes gold which contributed about 11 percent to the production value.

A paradoxical situation is occurring in these growing population areas which are demanding more construction minerals, and economic growth but are imparting restrictions upon access to new lands necessary to sustain and increase mineral reserves. Fortunately, California has a low-population area in the southern California desert which has a history and potential for mineral development and growth. A private economic report (1988) estimates that at least 40 different mineral products are derived from the California desert for a direct value of $1.3 billion. Applying benefits which also include indirect and induced effects it is estimated that these mineral productions have all added value of 75 percent for a total real value of $2.27 billion. Such values emphasize the economic importance of this area. However, as gold explorationists in 1978 focused their search upon the mineral potential of the southern California desert, and began to examine the historical and favorable gold districts, they found that here also the economic permissiveness was limited by access to exploration and development.

Today the California desert does not appear so formidable to travel. Highway and freeway travel replace the earlier limited rail access and provides a new ready access for a population seeking out the south west sunbelt. The Colorado river fulfilled a destiny of unimaginable agricultural diversity within previously desolate, arid val leys. The Arizona copper mining boom created population centers sustained by subterranean water resources. Travel through this once formidable California desert became ordinary.

In 1976, Congress promulgated FLPMA (Federal Land Policy Management Act) which recognized the increased pressures on the Californian desert and the need to protect unnecessary degradation. Congress thereby included as one of the mandates the CDCA (California Desert Conservation Area). After an exhaustive study, a multiple use plan was implemented in 1980 by the BLM (Bureau of Land Management) of California to administer the 25 million acres of the CDCA.

MESQUITE MINE DISCOVERY

Exploration interest recognized the antiquity of the Mojave Sonoran desert mineral history which originated with the quest of the Spanish Conquistadores for the fabled Indian cities of gold. Expeditions favored travel along the Colorado river and by 1780 Spanish placer mining camps were established in the nearby Yuma area. Mining continued in the early 1800's under the protection of the new Mexican government well before the Mexican treaty of 1848 and the California gold rush. Mining camps, focusing first on precious metals and later base metals, were discovered from the access route of the Colorado river.

GFMC (Gold Fields Mining Corporation), responding to the economic permissiveness of gold at this time, included the CDCA in their area of interests. An exploration office was established in Yuma, Arizona in 1980. GFMC noted three established gold districts in the CDCA. Two districts, one in the Cargo Muchacho mountains (American Girl mine) and the second near Picacho Peak (Picacho mine) had production records dating to the turn of the century. In 1980 GFMC found both these two mining districts to be under exploration by competitor companies. Incidentally, today both these districts have

gold production from heap leach operations managed by Eastmaque Gold Company and Chemgold Company. The third district, the Mesquite, had no history of previously recorded gold production. However, extensive shallow diggings related to the 1930's attest to continued interest by small companies and many individual lode mining claim owners, whose zeal persisted through the 1930's and extended into the 1980's. Numerous major mining companies were attracted into the Mesquite district, by the dedicated promotion of prospectors such as Ann and Dick Singer, George Burslem, Martha West, Charlie Wade, Virgil Kelly, Donald Blumtach and Charles Ham. In 1980, GFMC found that these companies, not withstanding various drillings and tests performed, had all abandoned their exploration activities. Reasons for such abandonment were the conflicting land holdings, insufficient ore grades, erratically exposed mineralization, and the general lack of size potential inferred by geologists looking for alteration and silicification which they had grown to expect from the Carlin gold camp in Nevada.

GFMC took a chance. This was based on a direct awareness of the tremendous potential for low grade gold extraction and recovery from. the new extractive technology of heap leaching which GFMC were experiencing and developing at their new Ortiz mine in New Mexico. Mesquite was found to have a rock type and structure similar to the Picacho mine which had been developed some 20 miles to the east. A low grade, high tonnage mineral potential appeared reasonable. The first Mesquite drill hole in September 1981 discovered significant gold mineralization. By November of 1982, and some 350 drill holes later, a world classsized gold reserve was announced as the Big Chief deposit.

Today, after some 3,400 holes and over 1,250,000 feet of drilling, production, which started in March of 1986, has expanded by 50 percent. Current mine planning integrates other newly discovered, lower grade satellite deposits, and optimizes the longevity of the Mesquite mine to the benefit of Imperial County.

MESQUITE MINE BENEFITS

To this date GFOC (Gold Fields Operating Co. - Mesquite) have expended $100 millionfor construction and development. The mine has a payroll of $8 million per year for 260 people of which about 80 percent come from the local area. Direct annual property tax to Imperial County is about $800,000 per year. It is estimated that one desert mining job adds another 1.6 jobs to Southern California. GFOC is estimated to be responsible for 700 mining equivalent jobs totaling some $22 million dollars in payroll. State and local taxes recover some $5.5 million dollars of this for direct social and economic benefits. GFOC plans to sustain its annual gold production at about 180,000 ounces. This allows the CDCA to contribute a real wealth of $72 million annually given a gold price of $400 per ounce. This is not money that is subsidized by government programs or contributed by taxpayer's dollars. There are no financial loans outstanding which may jeopardize future needy government allocations. No special state or county benefits have been expended. On the contrary, GFOC has required 25 local, state and federal permits to satisfy more than 400 stipulations and conditions in order to provide government agencies with all the assurance they require to administer and protect their various environmental concerns.

There is a sense of amazement for those recalling Mesquite in 1981, and comparing the immense benefits accrued from the Mesquite mine today in the relatively short production period of 3 years.

MINERAL DEVELOPMENT IS CAPRICIOUS

The Mesquite mine has defied probability, and stunned expectations. In short, it should not have happened. Government agencies had recorded the gold prospect locations, and the local community supported the persistence of the claim holders but many professional explorationists promoted their companys' negative mood. Such pessimism is well related by an anecdote which occurred in 1982 when an assistant to the Secretary of the Interior called the Gold Fields's Yuma office with a problem. How could he reconcile a mineral potential assessment report on the CMAGR (Chocolate Mountain Aerial Gunnery Range) prepared for the Department of the Navy with the Mesquite Mine discovery announcement. Both reports had arrived simultaneously on his desk. The CMAGR stressed no mineral potential within its bounds and alluded only to a few small 'gravel' deposits outside the CMAGR, whereas GFMC had just announced the discovery of a major gold deposit located within 1,000 feet southeast of the CMAGR boundary. Answers must be restrained diplomatically. Yes, GFMC did have 7 drill rigs delineating mineral reserves and it was all very real. So with due respect, one must acclaim success because of the economical, technological, and geological concepts which had changed in a very

short time. But in reality, and more importantly for reasons less likely to be credited, is that sense of optimism and foresight which overshadows the fundamental conditions and overrides pessimism.

Another example of the vagaries of exploration and the fortunes and misfortunes that could have affected the GFMC Mesquite mine discovery is the former inclusion of the Big Chief ore body within the Chocolate Mountain Aerial Gunnery Range. In the 1940's certain areas now within the CDCA were designated as Military Reservations. These areas are Ft. Irwin, China Lake, Chocolate Mountains, Twenty-Nine Palms and Edwards AFB. For the sake of convenience the southeastern boundary of the CMAGR was located along an old wagon trail which had become a road. In 1961 this boundary was moved from one half to one mile to the north so that the new highway 78, planned by the California Department of Highways would not be impacted. If this had not happened, the Big Chief deposit would have remained in the military reservation and could not have been discovered. Without the economics and infrastructure of the Big Chief deposit, the satellite deposits, south of the highway could not have been integrated into an economically feasible mine plan. Boundaries and roads are artificial and arbitrary and are not respected by mineral deposits. In that regard today, a new highway 78 has been relocated and dedicated to the State in July of 1988. This 8.5 miles of new highway is located about 3 miles to the south of the old highway in order to optimize operational activity between the deposits.

The foregoing history and current details relative to the Mesquite mine serve to illustrate that mineral potential depends on time and economic permissiveness. This Mesquite example is not an isolated case. Other examples of recent discoveries must be mentioned, so that one understands that exploration and discoveries are not predictable. Discoveries are unique. They will occur and they are important.

LAND AVAILABILITY IS PARAMOUNT

For these discoveries to occur, however, lands must be available for exploration. The CDCA is implied above, to be geologically permissive for successful mineral exploration. Currently, there is a desert protectionist movement sponsoring bill S11 in the legislature to reduce available public lands for exploration to such an extent, that exploration would almost immediately stop. The advocates for this non-mining and non-use concept say, "that all discoveries have been made, current mining would not be affected and California does not need additional mineral reserves." This is fanciful at the best and shows a lack of comprehension of exploration, and mineral economics, even by the consulting experts.

The following illustrations will try to depict the impact of such a conversion of explorable lands to parks or wilderness status. First, Figure 1, shows the outline of the 25 million acres of the CDCA within southern California and locates the combined withdrawn areas due to Military (3.1 million acres) and Parks (2.9 million acres).

Figure 2, locates past precious metal producers and the currently known economic gold-silver resources areas. Next, in figure 3, the areas considered to have the greatest potential for locatable minerals are shown. Currently, the area of public lands open to mining total about 9.7 million acres. Of this total, 5.9 million acres are available under strictly administered BLM protective regulations. It is evident that these restricted areas with exploration potential are bedrock areas or ranges. The deeply gravel covered valleys have limited potential for hardrock mineral development. Important mineral trends and structural patterns relate to these selections.

Figure 4 emphasizes that the BLM, during the CDCA implementation process, selected many of these more remote mountains ranges as WSA (wilderness study areas). The BLM after study found only about 1.9 million acres suitable for wilderness status. However, the S11 legislation advocates focused on these WSA for immediate conversion to wilderness status.

Figure 5 shows the impact of a combination of the current withdrawals and the proposed 'instant wilderness'. This withdrawn land proposal would increase from 7.9 million acres to 13.5 million acres. The total public lands available to mining would diminish to 4.1 million. The wilderness selection has been inadvertently screened to incorporate the areas with mineral potential.

The remaining areas for locatable minerals would now be severely limited. Such arbitrary

Figure 1
CDCA showing current withdrawn areas

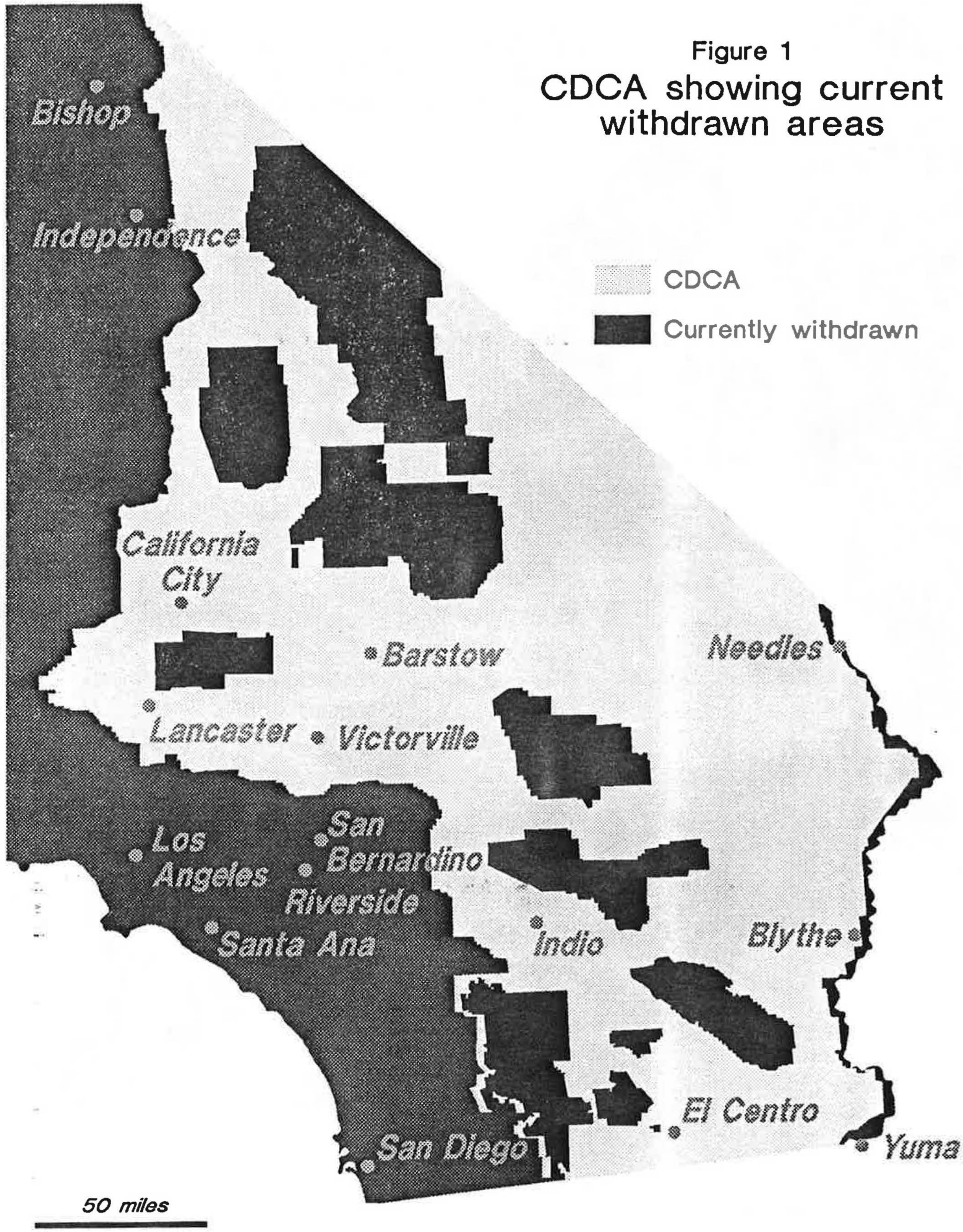
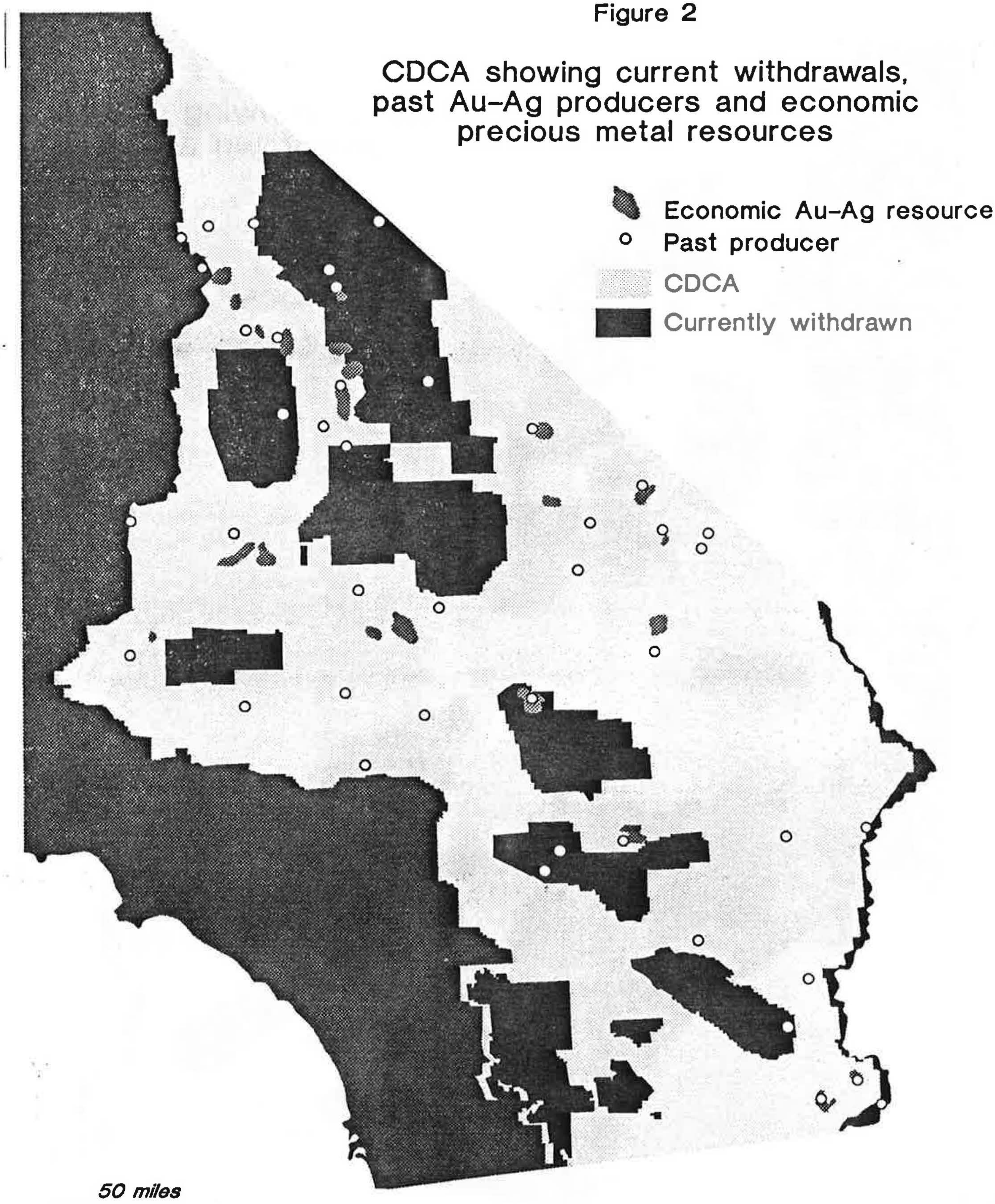


Figure 2

CDCA showing current withdrawals, past Au-Ag producers and economic precious metal resources



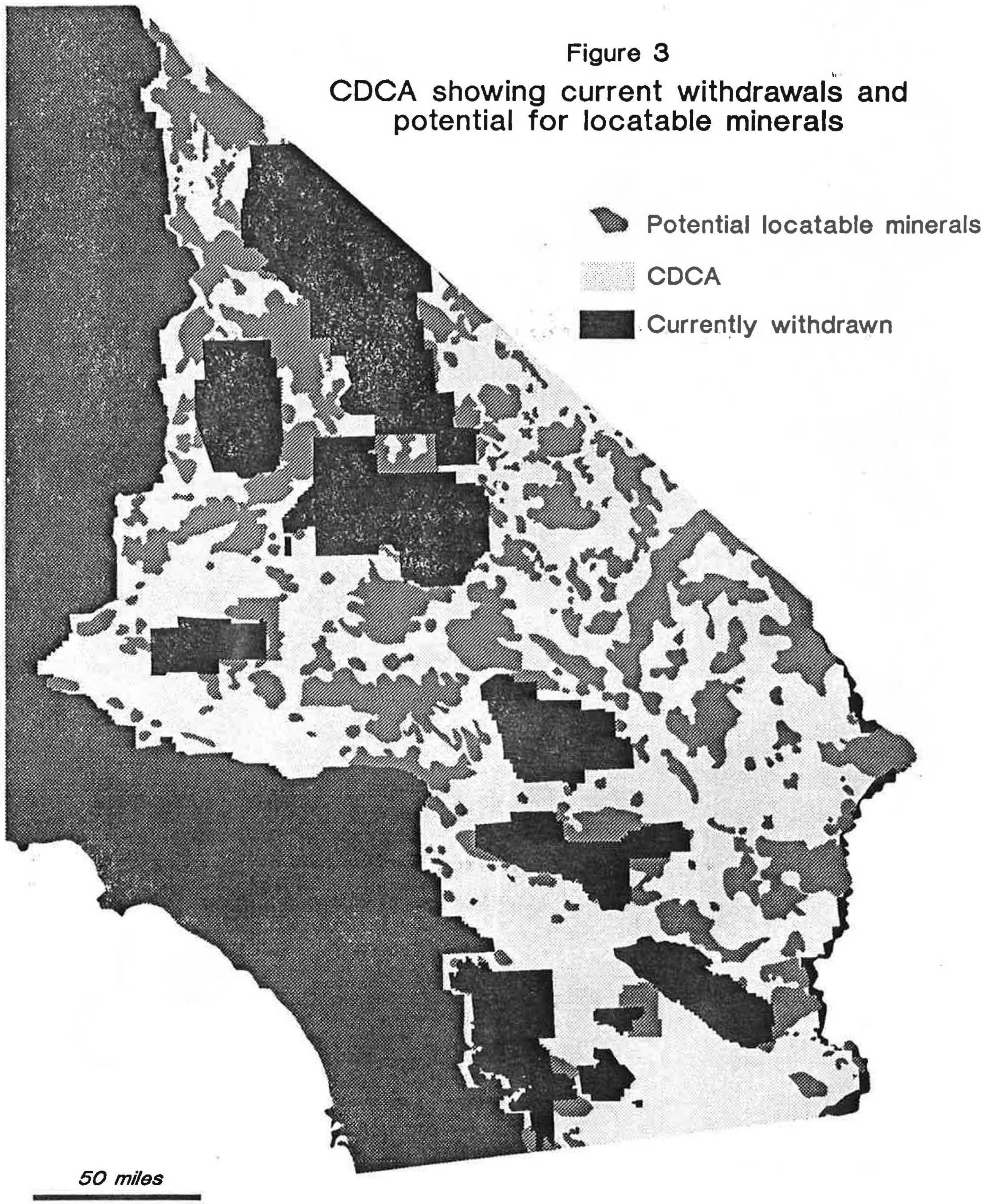


Figure 3
CDCA showing current withdrawals and potential for locatable minerals
Potential locatable minerals
CDCA
Currently withdrawn
50 miles

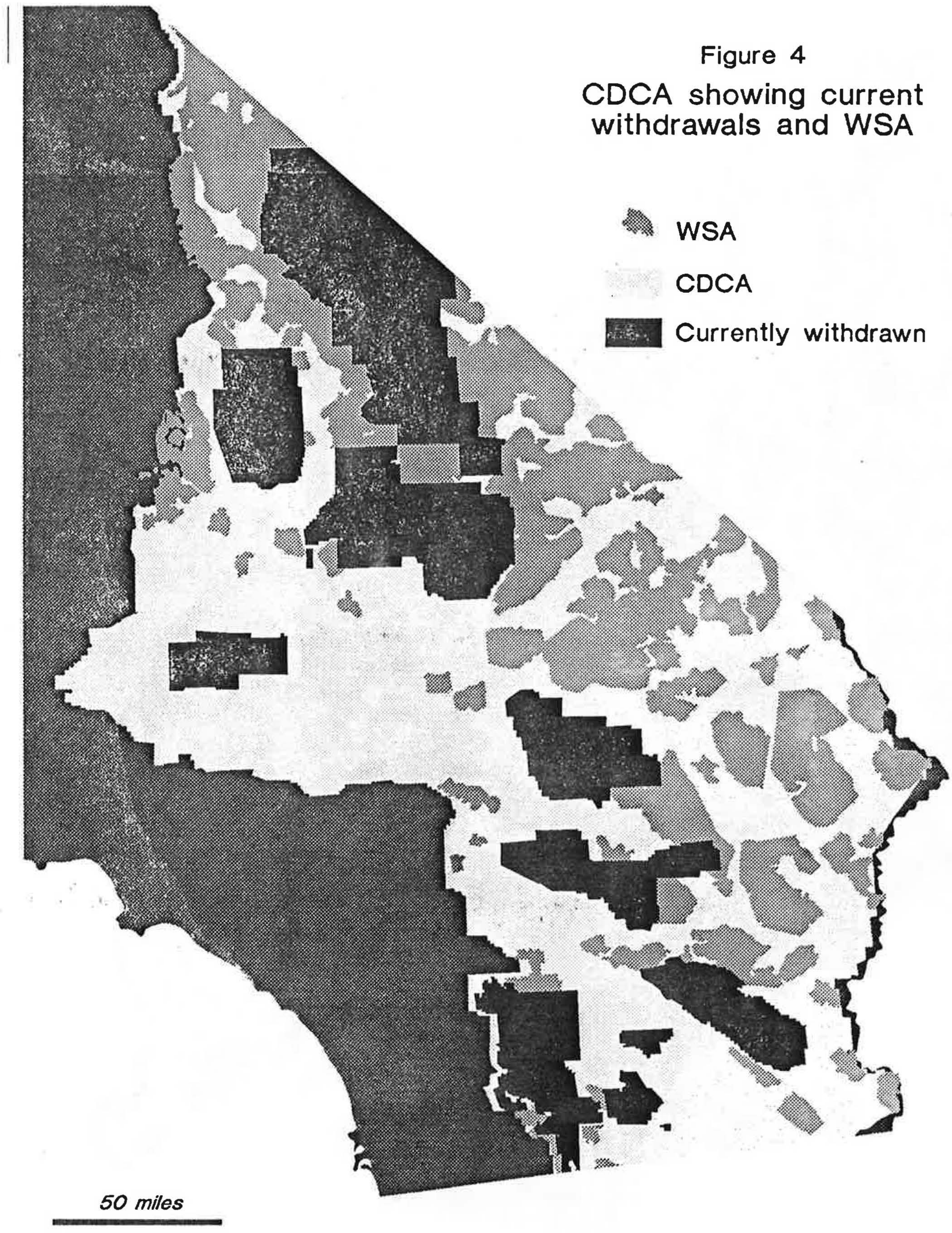


Figure 4
CDCA showing current withdrawals and WSA
WSA
CDCA
Currently withdrawn
50 miles

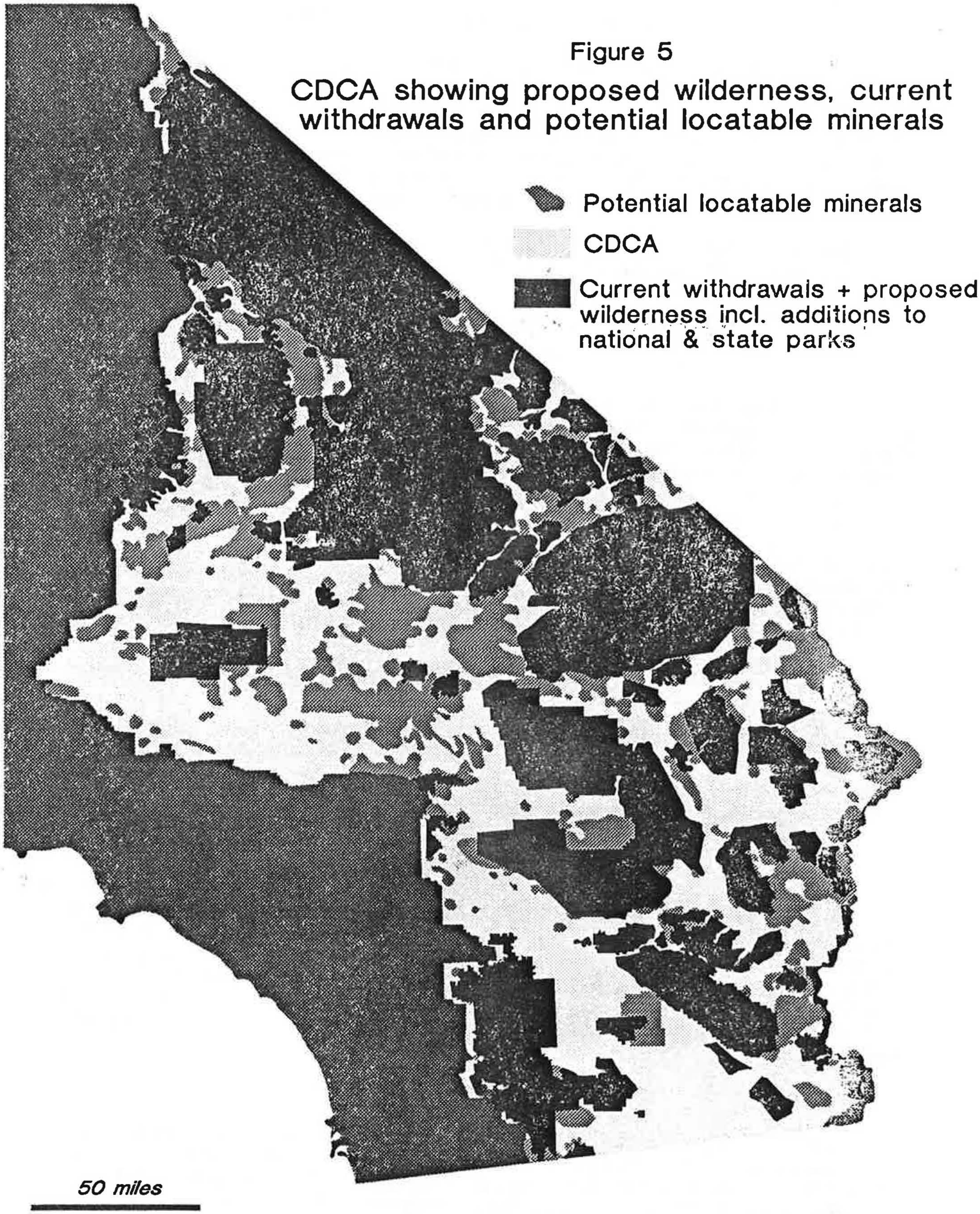


Figure 5
CDCA showing proposed wilderness, current withdrawals and potential locatable minerals
Potential locatable minerals
CDCA
Current withdrawals + proposed wilderness incl. additions to national & state parks
50 miles

mineral and land use policies defy the Mining Law of 1872. This form of land conservation is not a meaningful alternative for preservation, at the sacrifice of local jobs, continued economic progress in California and the protection of future national welfare.

MINERAL POTENTIAL IS NOT EXHAUSTED

Can it really be stated that California after its long history of mining has finally exhausted its mineral potentials? Investigations of government records suggest to some, that, because certain areas do not show the presence of mines or discoveries, therefore, mineral development potential must be extinct. Tell that to the prospector. It is not government agencies that find mines. They only report and describe them. It is the prospector, through untold efforts and preserverance through time, who brings a discovery to fruition. The entrepreneurship of risk capital takes a chance to develop a possibility. Finally, special technology and research solve problems to make the prospector's visions come true.

The mining industry does not suggest that all of southern California is mineralized. But, neither will it state that the 4,000 claim holders in the CDCA do not have the potential for viable mineral developments. Like Mesquite, some of these claims may prove discoveries. Areas not now staked will prove the presence of minerals and discoveries will follow.

CHIMNEY CREEK DISCOVERY

This is not speculation. This is fact. Exploration results are not predictable. Its analogy to research and development produce similar unpredictable discoveries. A set of examples from recent discoveries, will best prove this argument. Gold Fields' discovery of the Mesquite deposit in 1981 seems uncommon. But it takes the uncommon to make these discoveries. Gold Fields discovered the Chimney Creek gold deposit in 1984. This deposit is located north of the city of Winnemucca in Nevada. It is as large and as valuable as Mesquite. It also is unique and should not have happened. Prevalent geologic wisdom, acknowledging that the Preble, Pinson and Getchell gold mines to the south of Chimney Creek were located in rock formations of lower Paleozoic age, would not deign to explore a new structure in the unknown upper Paleozoic rocks of Pennsylvanian age. But the mine was there. Gold Fields geologists, not so dogmatic, following one weak gold value in the rock, eventually staked claims and discovered a new mine model for the records.

CASTLE MOUNTAIN DISCOVERY

Closer in time, Harold Linder of Viceroy Gold Corporation did not believe that the old Hart mining district in the CDCA had exhausted its mineral potential. The Castle Mountain gold deposit was discovered in 1986, the culmination of which was the discovery of the Jumbo deposit, completely buried and out of sight. This discovery required special foresight and effort. The discovery is reported to approach the initial Mesquite discovery in size.

HEMLO DISCOVERY

One of the most remarkable gold discoveries of recent time is the Hemlo deposit. This extremely rich, giant deposit was found in 1982, in Western Ontario on the north shore of Lake Superior. Canada's transcontinental freeway passes almost through the deposit. The old regional gold camp had been written off, since the original discoveries in 1869 and subsequent unsuccessful ventures. Sporadic staking and prospecting in 1973 to 1978 were finally followed by serious drilling in 1982. But it was only a handful of individuals who applying prudent exploration analysis and fortitude found in their drill hole number 75 the main ore bearing horizon, which now counts a gold reserve of about 23 million ounces valued at some $9.2 billion.

MINERAL PRODUCT RESEARCH

Mineral development is not only the story of persistent exploration but also of technological research and product development and marketing. Stainless steel is a product we have grown to accept and understand. Nickel which is a key element in the steel product alloy was isolated in 1751, but it was not until International Nickel Company began to research the alloy applications of nickel and steel after the turn of the century that an entirely new industry and market was developed.

A similar technological research and advancement has occurred in the CDCA. The Mountain Pass mine owned by Moly Corporation is unique in the world. Today it is supplying much of the free world's need for a series of rare elements who uses and benefits are becoming increasingly more valuable. It is unlikely that in 1951 when Moly Corporation acquired a small gold property with an obscure, so called 'rare earth' deposit that they imagined the harvest that their research would produce. There was virtually no market in 1951. The T.V. market after 1960 created a new and expanding demand. New color T.V. tubes are benefiting from these rare elements. New special alloy applications are being researched for future potentially invaluable utilization.

CARLIN GOLD TREND

Explorationists speak of metal logenic provinces, mineral belts, and structural trends. These suggest encouragement for mineral exploration and development. But they do not result in instant discoveries. Time is an ingredient that must play its role. The Carlin gold trend producers in Nevada have only in 1988 reported reserves and resources of gold from new discoveries which surpass the fabulous Hemlo gold deposit in total ounces assigned to precious mineral development. But in 1958, Carlin was merely an idea. It was a geologic idea mapped by Ralph Roberts of the survey as the Roberts Mountain Thrust. Gold possibilities were suggested along this structure. Newmont Mining Company began a gold sampling program along the presumably favorable horizon of the lower plate of lower Paleozoic limestones. In 1962 drilling identified the unique Carlin deposit which created a new gold model characterized by its submicroscopic gold particle size, which in the past had defied the old techniques of conventional prospecting and development. Production started in 1964 and a new regional industry was created.

Now 30 years after Ralph Roberts' mapping, new and larger deposits are being found along the Carlin gold trend. Some of these ore bodies are being found in formations quite different from the original Carlin model. Some of these ore bodies are now having the new technology of heap leaching applied. And some of these ore bodies are being found at greater depths than ever before considered for drilling. These are proving to be very rich and underground mining is proposed. Thirty years and exploration continues at a stimulated pace!

CONCLUSION

The few, but important examples of discoveries noted above attempt to portray the nature of exploration and mineral development. Every discovery has a story to tell and each has no counterpart when viewed as a phenomena of natural and extraordinary circumstances of probability. But successful exploration and mineral development is not entirely due to chance. It requires time, patience, tenacity, and above all a favorable permissiveness which encompasses economics, environment and most importantly access to land within a political system dedicated to the encouragement and administration of the opportunities of free enterprise for a common good.

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Chapter 4

RARE EARTH ELEMENTS AND SUPERCONDUCTIVITY

UNOCAL 76

MOLYCORP

LANTHOLOGY: APPLICATIONS OF LANTHANIDES AND THE DEVELOPMENT OF MOLYCORP'S MOUNTAIN PASS OPERATIONS

Paper submitted to the California Desert Mineral Symposium, Irvine, California, March 3-4, 1989, by Edmund C. Barnum, Manager, Technical Services, Molycorp, Inc, a Unocal Company, 1201 W. Fifth Street, Los Angeles, California 90017

Molycorp supports the efforts of today's symposium by the U.S. Department of the Interior, Bureau of Land Management, and the South Coast Geological Society to increase the public awareness of our desert mineral resources. In 1988, Molycorp financially supported the Desert Conservation Institute which was an educational project of the California mining industry. The DCI worked closely with other desert groups in opposing the passage of Senate Bill 7. This coalition that opposed SB7 included rock hounds, RV users, large and small mining companies, ranchers, developers, railroads, suppliers, senior citizens, the teachers pension fund, the BLM, local and county governments as well as key congressional support. Molycorp was pleased to host visits in 1988 to our Mountain Pass mine, located 12 mines this side of Nevada adjacent to I-15, by two congressional delegations as well as the Secretary of the Interior, Mr. Donald Hodel. Our lanthanide operations represent almost exclusively new high technology market applications that have developed in the last twenty-five years. The next twenty-five years should continue to bring new applications from superconductors to ideas not yet on paper and are the reason we cannot lock away our desert resources. It is a safe prediction that the patent office will continue to be busy.

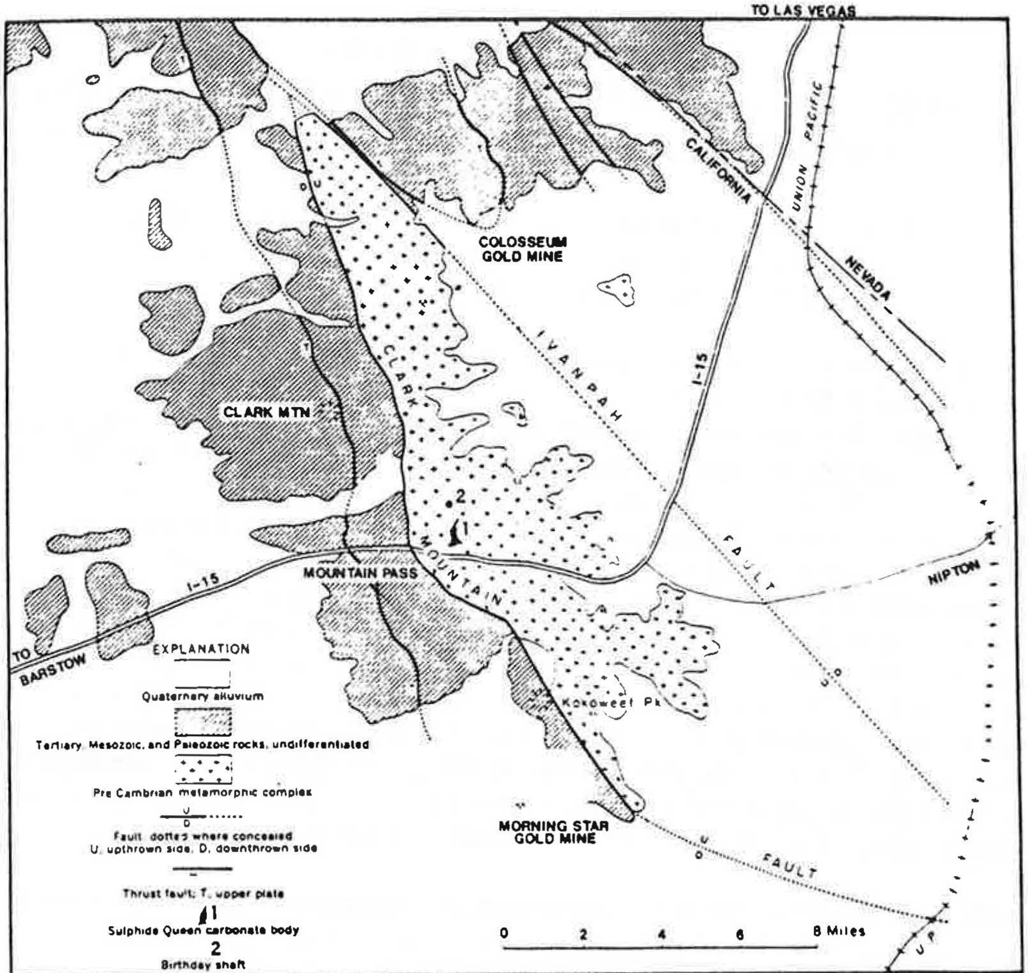
Lanthology is a word not yet found in many dictionaries. At least, scientists are finally making progress with the growing acceptance of the term **lanthanides** as the strategically important family of elements closely associated in nature and the periodical table, atomic numbers 57 through 71. These elements are neither rare nor are they earths. The lanthanide business is not a very big mining or chemical business compared to copper or ethylene, but the wide range of applications from art to national security make it very interesting. The business is also very competitive with strong efforts supported in France, Japan, China, and Australia. Molycorp is fortunate because of our long history of working with consumers to develop markets and processing an excellent orebody to be the major supplier of the world,s lanthanide needs.

Molycorp's **lanthanide** operations in Mountain Pass are located in an area with a long history of mining activities dating back to silver operations that began in 1865. Between 1900 and 1920 many small lead, zinc, copper, gold and tungsten mines operated in the Clark Mining District. The Sulphide Queen gold deposit, adjacent to Mountain Pass, was discovered in 1936 and is shown on the map below as the Birthday shaft. A 100-ton cyanide plant was built, but little gold was produced. The area supports two active gold mines, the Colosseum and the Morning Star. The Colosseum mine is now producing 6,000 ounces of gold per month.

Despite considerable mining exploration activity in the Clark Mountain area, the presence of lanthanides was not suspected until 1949. Herbert Woodward and his partner, Clarence

Watkins, discovered a heavy, light-brown mineral on claims nearly a mile north of the Sulphide Queen gold mine. This mineral was identified as **bastnasite,** a fluorocarbonate.

The U.S. Geologic Survey confirmed the bastnasite discovery, and Molycorp purchased the claims in February, 1950. In the course of mapping the Mountain Pass area in 1951, the USGS discovered an enormous bastnasite deposit, mostly on the Sulphide Queen claims. Molycorp purchased the Sulphide Queen property and several adjoining mining claims.



GEOLOGIC FEATURES OF MOUNTAIN PASS DISTRICT
(map modified from U.S.G.S. P.P. 261, Rare Earth Mineral Deposits of Mountain Pass)

The Sulphide Queen orebody is contained within a highly differentiated alkaline carbonatite which is distinguished by an exceptionally high content of lanthanides. This Precambrian carbonatite mass is associated with potash-rich alkaline intrusions of syenitic to shonkinitic composition. These igneous rocks were intruded into metamorphic gneisses along a six mile NW-SE trending linear belt. The carbonatite mass has a strike length of about 2,300 feet and a thickness exceeding 200 feet. The body dips about 40° to the west. The typical ore contains about 40% calcite, 25% barite and/or celestite, 10% strontianite, 12% bastnasite, and minor amounts of other minerals.

The bastnasite mineral at Mountain Pass contains 14 lanthanides and yttrium. On average, the bastnasite ore reserves contains nearly 9 percent lanthanides. For every ton of bastnasite ore mined, Molycorp is able to recover about 100 pounds of lanthanides. The Mountain Pass orebody has 31 million tons of proved and probable reserves based on a five percent cutoff grade.

The lanthanides are distributed in the ore as follows:

Cerium	49.0%
Lanthanum	32.9%
Neodymium	13.0%
Praseodymium	4.0%
Samarium	0.5%
Gadolinium	0.2%
Europium	0.1%
Yttrium/Terbium	0.1%
Others	0.2%

Surface mining methods are employed to produce up to 2,000 tons of crushed bastnasite ore per day. Ore and waste are loaded into 35-ton haulage trucks with wheel loaders.

The lanthanides are concentrated, refined and separated at Mountain Pass. The bastnasite ore is first crushed to less than 5/8-inch in size. This crushed ore is conveyed to stockpiles and layered for blending, then hauled to the flotation plant. Grinding with a ball mill frees the mineral grains for separation by using a Molycorp-developed froth flotation process. This yields a concentrate containing 60 percent lanthanide oxides. This lanthanide concentrate is then thickened, filtered, dried and stored in bulk or packaged for shipment.

To separate the individual lanthanide oxides, Molycorp utilizes solvent extraction. This is a continuous multi-cell process using counter current flows of organic and aqueous solvents for separating the various lanthanides.

Today, Molycorp's Mountain Pass operations are the only deposit of its kind mined solely for lanthanides, and the largest deposit of these important elements in the western world. The commercial availability of these lanthanides from Mountain Pass has led to the development of many new products.

The most important invention in the evolution of Mountain Pass was the commercialization of color television in the mid-1960's. The red phosphor component in all color television sets and and now computer monitors is made from **europium** and **yttrium** oxides. The overiding consideration of the original processing design was the most economical method to produce europium oxide.

Prior to the invention of color televisions, lanthanides were not separated in significant commercial quantities using solvent extraction. Early applications included mischmetal or mixed metal in lighter flints that sparked because of the **cerium**. Other early applications included using mischmetal or"rare earth" silicide in iron and steel for sulfur control. These **cerium** rich alloys improved the ductility of cast iron and increased the strength of automotive and pipeline steels. This high volume application peaked in the early 1970's before continuous casting became important in the production of steel.

Another large volume application that has declined is the use by petroleum refineries of cracking catalysts that contain a **lanthanum**-rich lanthanide mixture to increase the yield of gasoline and other aromatics from heavy crude oils. This application peaked in 1984 and started declining after the U.S. government ordered a phaseout of lead in gasoline. Refineries switched to cracking catalysts with less lanthanum that resulted in lower gasoline yields and shorter catalyst life but increased the octane of the gasoline produced.

The need for cleaner air on the other hand has also created a strong new market application for lanthanides. Automotive exhaust catalysts rely on cerium-containing ceramic components for longer life. This market is growing in both Japan and Europe as well as the United States. To meet this growing demand for high purity cerium, Molycorp added capacity at Mountain Pass in 1988.

Another strong growth area for lanthanides has been high strength permanent magnets. In the late 1970's and early 1980's, **samarium** alloyed with cobalt made possible lighter, smaller, and more energy efficient electric motors. These magnets are integral parts of the design of missile guidance systems, computer disc drives and portable tape players. Still new, more powerful permanent magnets are derived from a **neodymium**-iron-boron alloys developed in the early 1980's. Neodymium is more abundant than samarium and the neodymium magnets do not depend on cobalt imports from Africa and the USSR. As a result, neodymium magnets will be able to replace many of the traditional applications of ferrite magnets. Neodymium and samarium are other examples where Molycorp made significant capital expenditures at Mountain Pass to provide additional separation capacity to supply the needs of a growing industry. Our engineers and scientists worked closely with other companies through the research, development, and production stages to assure an adequate raw material supply for companies in the United States, Europe, and Japan. It is this ability that has enabled our company to remain competitive with more abundant resources in China.

Glass and ceramic applications continue to be important market applications for lanthanides with moderate growth especially in **yttrium**-stabilized zirconia ceramics. The bright yellow glaze on ceramic tile and sanitaryware is derived from a calcined mixture of **praseodymium** and zirconium oxide. **Neodymium** is used to maintain stable electrical properties over a wide temperature range in ceramic capacitors. High quality glass camera lenses and optical fibers transmit more light with less distortion due to use of **lanthanum** oxide. Glass containers and tableware use cerium as a decolorizer to achieve a "water white" transparency. Cerium oxide is the universal compound for the precision polishing of glass used in ophthalmic lenses, camera lenses and television faceplates. **Neodymium** can be used to enhance the picture brightness and contrast of color television faceplates.

The other significant market application group for lanthanides is phosphors. Besides color televisions, **europium, yttrium, cerium,** and **terbium** containing phosphors are used to simulate natural daylight conditions and reduce energy consumption in fluorescent lamps. Medical x-ray intensification screens containing **lanthanum**- or **gadolinium**- based phosphors reduce patient diagnostic exposure times by more than half.

Other lanthanide applications are strategically important to the defense of the United States. **Yttrium** is needed for YIGs and YAGs for defense communications equipment. Jet engine coatings and superalloys need **yttrium, lanthanum,** and **cerium.** Neodymium and yttrium lasers are common. **Samarium** and **gadolinium** are needed in traveling wave tubes for satellites. **Gadolinium** is also used in permanent computer bubble memories, GIGs and GAGs for microwave filtration, and nuclear reactor control rods. **Terbium** and **dysprosium** are used in a new submarine sonar alloy. **Erbium** is under development in a titanium alloy for advanced tactical fighters. While the actual pounds of these applications is small, it is vital not to be dependent on foreign countries for these materials.

The last applications to be discussed today are high-temperature superconductors which are not very important now but could turn out to be the most important. The 1988 Nobel prize for physics is a symbol of the large research efforts by major corporations, universities, and national research labs in Europe, Japan, and the United States. Potential applications include supercomputers, transportation, and electrical energy transmission. **Yttrium** and **lanthanum** are needed in many of these new ceramic compounds.

Molycorp, Inc., a Unocal Company, has headquarters in Los Angeles and sales offices in White Plains, New York; Washington, Pennsylvania; Paris, France; and Tokyo, Japan. Other lanthanide processing plants are located in Louviers, Colorado., and York and Washington, Pennsylvania.

Molycorp is also a primary producer of molybdenum and holds a 45 percent interest in CBMM of Brazil. CBMM is the world's major supplier of niobium. Molycorp is also responsible for coordinating worldwide mineral exploration for Unocal and its subsidiaries.

RARE EARTH MINERALS, SUPERCONDUCTIVITY, AND THE CALIFORNIA DESERT

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Summary

Rare earths are a group of elements used in the petroleum, metallurgical, and glassmaking industries. Significant further possibilities for rare earth consumption lie with superconductivity applications, although commercial use of these elements is not imminent.

Virtually all domestic production and most of the reserves of rare earths are located at the Mountain Pass Mine in the California Desert Conservation Area outside of new park and wilderness areas proposed under the California Desert Protection Act (S. 11). Reserves of rare earths from this mine could last more than 500 years at current levels of domestic consumption. If demand for rare earths rises much more quickly than the U.S. Bureau of Mines has projected, there are many identified and projected sources of supply for rare earths in this country and North America.

Introduction

Rare earth elements are important mineral commodities with domestic production centered at one location in the California Desert Conservation Area. This report describes the rare earth minerals and their uses. Particular emphasis is placed on the quantity and location of domestic sources of rare earths, especially the rare earth elements located in the California Desert.

What are Rare Earth Elements?

Fifteen commodities are collectively termed the rare earth elements. These elements, having similar chemical and physical properties, are identified as elements 57 through 71 in the periodic table of elements. They are further classified as light and heavy rare earth elements.

TABLE 1- Light and Heavy Rare Earth Elements

Light Rare Earths	Atomic Number	Heavy Rare Earths	Atomic Number
lanthanum	57	gadolinium	64
cerium	58	terbium	65
praseodymium	59	dysprosium	66
neodymium	60	holmium	67
promethium	61	erbium	68
samarium	62	thulium	69
europium	63	ytterbium	70
		lutetium	71

Two principal types of ores -- bastnasite and monazite -- contain the rare earth elements mined in the United States. Virtually all of U.S. rare earth element production comes from

bastnasite, and this ore type also accounts for most rare earth reserves[1] (U.S. Bureau of Mines, 1985, *Mineral Facts and Problems*, p. 651). Bastnasite is a hardrock ore that contains rare earths combined with fluorine, carbon, and oxygen. Open pit mining methods are used to extract this ore.

Monazite is an ore type consisting of rare earth elements combined with phosphorus and oxygen and found in highly concentrated deposits, usually beach sands. Only a small fraction of U.S. rare earths production and reserves are obtained from monazite. Indeed, rare earths are produced only as a byproduct when these beach sands are mined. Domestic monazite deposits are primarily exploited for their titanium and zirconium content.

Uses of Rare Earth Elements

Currently, a great deal of scientific research and public attention are being directed toward the field of superconductivity. Superconducting material can transmit electricity much more efficiently than copper and other substances in wide use today. As a result of this greater efficiency in electrical transmission, significant cost savings may be realized as less fossil fuel or nuclear power will be required to generate the same amount of electricity. In addition, specific applications for superconducting material will likely be found in electric motors, lighting, electromagnets, magnetically levitated trains, and a host of other electrical uses.

Functioning superconducting devices now exist. Unfortunately, most of them require very low operating temperatures that can only be maintained through the use of liquid helium, a costly coolant. Attempts are thus being made to find materials that exhibit superconducting properties at or near room temperature. One of the technologies uses a material composed of barium, copper, oxygen, and the rare earth lanthanum. Interestingly, as of this writing, the material showing superconducting properties at the highest temperature contains bismuth, but no rare earth elements.

Although breakthroughs in room temperature superconductivity have occurred, actual devices to achieve this goal are far from commercial application. All experimentation is still at the laboratory scale. Substances that do show superconductivity at elevated temperatures typically exhibit this property only within a small portion of the material.

Superconductivity experiments account for an immeasurably small fraction of rare earth consumption in the U.S., however. These elements have a number of other uses, as displayed in Figure 1. In 1986, almost half of rare earths used domestically were employed in the petroleum industry (U.S. Bureau of Mines, 1987, *Mineral Commodity Summaries*, p. 126). Rare earths in this industry aid in cracking long hydrocarbon chains of crude oil into smaller, less complex hydrocarbons such as gasoline, diesel fuel, kerosene, and other products.

About one-third of U.S. rare earth consumption during 1986 helped impart special properties to iron and steel and other metals. Such metallurgical applications allow for control of the sulfur and oxygen content in the metals. Moreover, rare earths improve the cold formability, impact resistance, high temperature oxidation resistance, and other attributes of the final steel products.

The glass-making industry is also a major consumer of rare earths. In 1986, 18 percent of U.S. rare earth consumption was used as colorizing and decolorizing agents and to provide protection from ultraviolet radiation in various types of glass. Other rare earth elements contribute to phosphors in color television sets, and as components in electronic devices and in permanent magnet electric motors.

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[1]Reserves are identified minerals that are economic to produce under current market conditions and may be mined in future years.

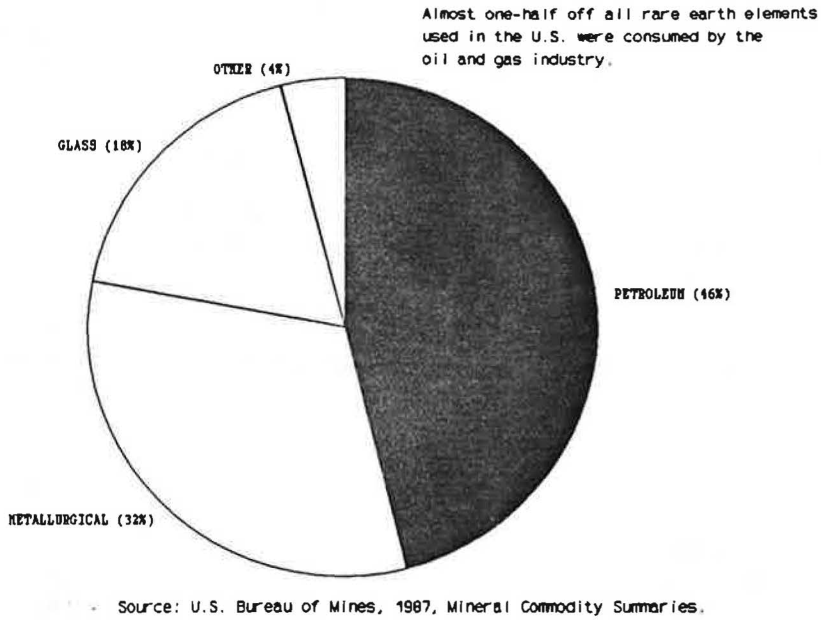

Figure 1- U.S. Consumption of Rare Earth Elements, 1986

Domestic Sources of Rare Earth Elements

Approximately 97 percent of U.S. and 33 percent of world rare earth elements production in 1986 came from one mine located in the California Desert Conservation Area (U.S. Bureau of Mines, 1987, *Mineral Commodity Summaries*, p. 126). The Mountain Pass Mine is 50 miles west of Las Vegas, Nevada, in the Clark Mountains of eastern California. Ore grade at Mountain Pass averages 12 percent bastnasite, making it the richest grade mine of rare earths in the world (U.S. Bureau of Mines, 1985, *Mineral Facts and Problems*, p. 651).

Reserves of rare earth elements at Mountain Pass total 3.6 million tons of rare earth oxides (REO) (U.S. Bureau of Mines, 1985, *Mineral Facts and Problems*, p. 651). Total U.S. consumption of rare earths in 1987 was 10,300 tons REO, a five-year low (U.S. Bureau of Mines, 1988, *Mineral Commodity Summaries*, p. 126). At this rate of consumption, identified reserves of rare earths at the Mountain Pass Mine alone could supply the needs for the entire country for 534 years.

As a benchmark portraying the enormous size of the rare earths reserves, Table 2 (depicted graphically in Figure 2) shows the corresponding U.S. consumption and reserves for several other more common commodities. The identified reserves of rare earths exceeds the level of identified reserves for other commodities as much as 80-fold.

TABLE 2- U.S. Reserves and Consumption of Selected Minerals, 1987				
Commodity	Unit	Domestic Consumption	Domestic Reserves	Reserve to Consumption Ratio
				(years)
Rare Earths	tons	10,300	5,500,000	534
Copper	tons	2,190,000	57,000,000	26
Gold	ozs.	2,800,000	117,000,000	42
Lead	tons	1,130,000	11,000,000	10
Silver	ozs.	144,000,000	920,000,000	6
Zinc	tons	990,000	21,000,000	21

Source: U.S. Bureau of Mines, 1988, *Mineral Commodity Summaries*, various pages.

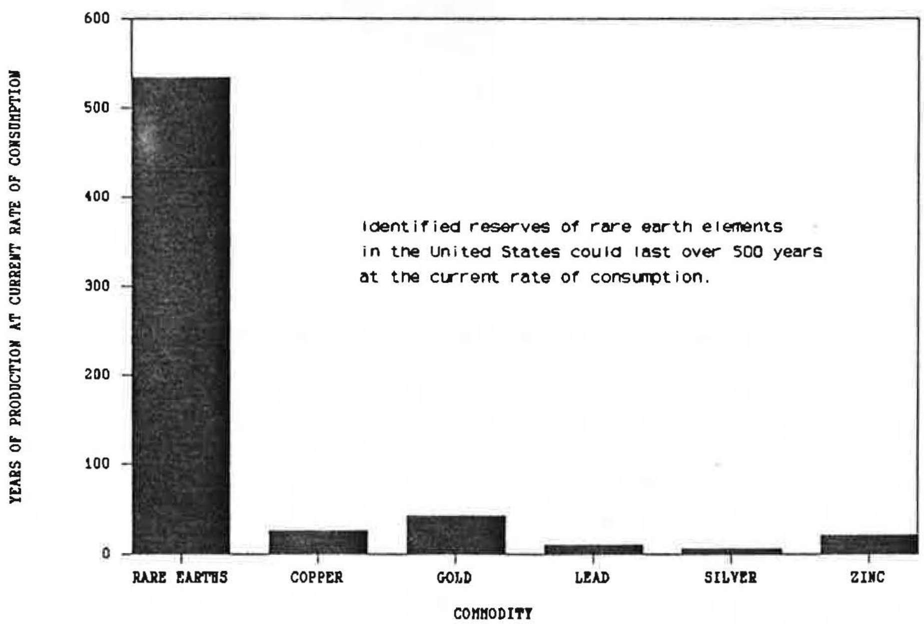

Figure 2- Adequacy of Current U.S. Reserves for Selected Commodities

Although the U.S. has identified reserves of silver for only six years at the current consumption rate, no one is mounting an exhaustive exploration campaign for this precious metal because current stocks, sources of reliable imports, and domestic sources of secondary metal are considered adequate. Another notable feature is that all of the selected commodities, except for rare earths, have domestic reserves in tens or even hundreds of mines throughout the country. Currently, virtually all domestic reserves of rare earth elements are located at the Mountain Pass Mine. This measure of apparent rare earth abundance could be misleading if these elements are exhibiting a dramatic growth in consumption. However, overall demand, and especially petroleum refining, the major single use of rare earth elements is currently declining in this country and may continue into the future.

It is conceivable that the demand for rare earth elements could rise significantly if superconductive technologies are implemented. This increase in demand could occur even though the current major use for rare earth elements, as catalysts in petroleum refining, has been decreasing and is projected to continue a downward trend. Increased demand would provide an incentive for further exploration for rare earths. However, even if domestic consumption of rare earth elements tripled over the 1988 level, currently known national reserves could supply domestic needs for over 175 years. Under the current demand scenario, it is unlikely that many new sources of rare earth elements will be utilized in this country.

Yet, known sources of rare earths exist in the U.S. outside of the Mountain Pass Mine. Byproduct recovery of rare earth elements from iron ore tailings in New York and New Jersey and phosphate rock in Florida and Idaho could occur if high levels of demand develop (U.S. Bureau of Mines, 1985, *Mineral Facts and Problems*, p. 663). In addition, large resources of monazite and other heavy mineral sands containing rare earths off the Atlantic Coast could be a major source of supply. As the U.S. Bureau of Mines states "[T]he overall assessment is that the United States can be self-sufficient in rare earths...[the U.S.] possesses the world's largest production and separation capacity, and total North American reserves and resources are large" (U.S. Bureau of Mines, 1985, *Mineral Facts and Problems*, p. 659).

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CALIFORNIA DESERT MINERALS, SUPERCONDUCTORS, AND OTHER ADVANCED MATERIALS

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Introduction

The decade of the 1980's has seen "advanced materials" become a key factor in international competition among the industrialized nations, with the United States, Japan, and the European Economic Community being the major competitors. A consensus is developing that the industries that are first to commercialize the large array of new structural materials and electronic, optical, and magnetic materials and devices will be those who determine the structure of national and world economics. Many technical, economic, legal, political, social, and cultural factors are important determinants in the race to commercialize new materials. Millions of words have been written about these factors and their interdependence; yet the sheer complexity of the problems, the rate at which changes are taking place, and the economic risks involved are so great that government policy makers and industrial decision makers find adequate understanding to be very difficult.

Of the many factors involved in advanced materials, the Bureau of Mines has the statutory responsibility to provide information on where materials can be found and how they are mined, extracted, purified, combined, and recycled. It is obvious that minerals availability is essential to implementation of any new technology just as there can be no commodity metals industry if the ores are not available. Because "minerals availability" for advanced materials is considerably more complex than for commodity materials, the divisions and branches of the Information and Analysis directorate of the Bureau of Mines are redirecting resources to provide reliable information for policy and decision making. The Office of Advanced Materials Coordination was established in July 1987 to coordinate and assist these efforts. The key issues and problems have been defined and the role of the Bureau has been outlined (Sorrell, 1987, 1988). The purpose of this paper is to provide definitions of advanced materials, a summary of major issues andproblems, an overview of minerals availability, a perspective on the importance of known and potential mineral resources in the California desert lands, and a discussion of rare earth elements and their importance for the new superconductors and other advanced materials.

Advanced Materials—Definitions and Classifications

The Bureau of Mines (Sorrell, 1987) defines advanced materials as those developed during the past 30 year or so, and being developed at present, that exhibit greater strength, higher strength-density ratios, greater hardness, or superior thermal, electrical, optical, or chemical properties, when compared to traditional materials. Advanced metals, ceramics, and polymers, including composites of these, promise to decrease energy consumption, improve performance at lower cost, and lessen dependence on imports of strategic and critical materials. New electronic, magnetic, optical, and chemical devices, engineered at the molecular level, are resulting in a revolution in communications, data analysis, chemical and structural analysis, medical technology, and industrial processing that promises dramatic changes in manufacturing and human lifestyle.

The Bureau classifies advanced materials as metals and alloys; structural ceramics; engineering polymers; advanced metal, ceramic, and polymer composites; electronic, optical, and magnetic materials and devices; and medical and dental materials.

Issues and Problems

Materials Availability. In addition to information on minerals production, which is a primary responsibility of the Bureau, there are other areas of concern which have not been addressed in a systematic and continuing manner. Although some advanced materials, such as silicon carbide and silicon nitride, are made of abundant raw materials, they are not necessarily available as high-purity, submicrometer particles needed for production of high-quality, reliable components. The processing capacity of U.S. industry and the extent of reliance on imports of these materials need to be assessed.

Other materials are imported and then processed to produce purified materials for manufacture of advanced products. These materials need to be identified, and a method needs to be developed to determine what portion of imported raw materials goes to sustain new materials development and manufacturing. Several raw materials will find new uses in advanced materials, particularly in electronic, magnetic, optical, and superconductor devices. The potential for increased use of these materials needs to be assessed so that availability and U.S. dependency on imports can be assessed reliably.

Byproduct Availability. A related problem of materials availability is that byproduct elements used or likely to be used in advanced materials, particularly electronic and optical devices and in sensors, are obtained wholly or in part as byproducts of other materials such as aluminum, copper, lead, zinc, and iron. Among these are gallium, germanium, indium, cadmium, thallium, arsenic, bismuth, zirconium, hafnium, and the rare earths. Availabilities of these elements are directly linked to production of commodity materials, so effects of materials substitution and overall use patterns on byproduct availability need to be estimated and reported.

Waste Materials Recovery. Inadequate attention has been given to the technology and economics of recycling advanced materials or the waste products from manufacturing processes and to the toxicity of some of the elements. Electronic, magnetic, and optical materials contain expensive elements, such as gallium, germanium, and indium, and the most-toxic elements, such as mercury, thallium, cadmium, and arsenic. Therefore, it is imperative that technology for recovery is improved, the magnitude of the environmental problem is assessed, and responsible governmental agencies and legislators receive reliable information for policy decisions based on a balance between environmental and national security considerations. Waste materials, such as coal fly ash from power generation and red mud from Bayer processing of bauxite, contain not only appreciable quantities of commodity materials such as aluminum, titanium, and iron, but also valuable minor elements such as gallium and germanium. The technology and economics of recovery of these elements should be reexamined in light of advanced materials developments.

Effects of Substitution. Forecasting the impacts of new materials development on traditional commodity materials, based on acquisition and analysis of data on materials use, has received inadequate attention, and efforts to anticipate future substitutions on the basis of current research have been inadequate. It is necessary to monitor the whole path of new materials from the earliest research stages through development, pilot plant, and production. Given the proprietary nature of such information and reliance on voluntary reporting, this is a difficult task but one which needs to be attempted.

Research Needs. Some of the Minerals needed to produce advanced materials are found only in low-grade deposits in the U.S. Research is needed to find economical methods to extract and process these low-grade ores to reduce the Nation's dependence on foreign sources of supply. New advanced materials provide an opportunity for significant advances in mining and mineral-processing technology and safety, such as improved cutting tools, new components for internal combustion engines to increase fuel efficiency and useful life, remote-sensing devices, solid-state processors and controllers for robotic operations, and new materials for abrasion-resistant conveyer belts. The Bureau is expanding its efforts to investigate possible applications of advanced materials in existing programs aimed at advancing mining and mineral-processing technology.

Requirements for Advanced Materials. A careful examination of the literature on advanced materials to determine what elements are used uncovers an interesting, if not surprising, fact: about two-thirds of the elements found in minerals are listed. See Table 1. The uses of these have been compiled by the Bureau of Mines (Sorrell, 1987).

When those elements not normally considered to be mineral commodities (oxygen, nitrogen, fluorine, chlorine, etc.) are included, the list is seen to include all the common elements and many relatively rare ones. For the majority of the elements, availability is not an issue but for many of the less common elements, the problems are severe and complex. Among these are:

- Natural abundance and geographical distribution. Are domestic reserves or those available from reliable sources adequate to sustain the technology?
- Byproduct availability. If commodity materials production declines, will recovery of byproducts be economically feasible? Many elements—e.g. Sb, As, Bi, Cd, Ga, Ge, Hf, In, Re, Sc, Se, Te, Ti, Y, and the rare earths (with one exception)—are byproducts. These same elements are essential to electronic, optical, and magnetic materials and devices.
- Processing capability. As already mentioned, availability of the elements is of no importance if separation, purification, and fabrication capabilities are not available.

Table 1. Elements use in advanced materials and devices.

Aluminum	(Al)	*Holmium	(Ho)	Rubidium	(Rb)
Antimony	(Sb)	Indium	(In)	Ruthenium	(Ru)
Arsenic	(As)	Iodine	(I)	*Samarium	(Sm)
Barium	(Ba)	Iridium	(Ir)	Scandium	(Sc)
Beryllium	(Be)	Iron	(Fe)	Selenium	(Se)
Bismuth	(Bi)	*Lanthanum	(La)	Silicon	(Si)
Boron	(B)	Lead	(Pb)	Silver	(Ag)
Cadmium	(Cd)	Lithium	(Li)	Sodium	(Na)
Cerium	(Ce)	*Lutetium	(Lu)	Strontium	(Sr)
Cesium	(Cs)	Magnesium	(Mg)	Sulfur	(S)
Chromium	(Cr)	Mercury	(Hg)	Tantalum	(Ta)
Cobalt	(Co)	Molybdenum	(Mo)	Tellurium	(Te)
Columbium	(Cb)	*Neodymium	(Nd)	*Terbium	(Tb)
Copper	(Cu)	Nickel	(Ni)	Thallium	(Ti)
*Dysprosium	(Dy)	Osmium	(Os)	*Thorium	(Th)
*Europium	(Eu)	Phosphorus	(P)	Tin	(Sn)
*Gadolinium	(Gd)	Platinum	(Pt)	Titanium	(Ti)
Gallium	(Ga)	Potassium	(K)	Tungsten	(W)
Germanium	(Ge)	*Praseodymium	(Pr)	Vanadium	(V)
Gold	(Au)	Rhenium	(Re)	*Yttrium	(Y)
Hafnium	(Hf)	Rhodium	(Rh)	Zirconium	(Zr)

* Yttrium and the rare earth elements.

Mineral Potential of California Desert Lands. The Bureau of Mines and the Geological Survey (1988) have identified known deposits and rated the mineral potential of the proposed wilderness areas in the Southern California Desert lands. In addition to industrial chemical and construction materials in abundance, this highly mineralized area has known and highly potential reserves of precious and commodity metals (Au, Ag, Cu, Pb, Zn, Fe, Mn, W) and, by inference, the byproducts (Ga, Ge, In, Ti, Bi, Sb, As, etc.). Of importance to the development of advanced materials is the actual or potential existence of deposits containing the relatively rare elements (Y, the rare earths, Hg, Th, Ti, Be) and less rare elements (Ba, Sr, Li).

Three important prints should be made about the mineral deposits of the California deserts:

- For many of the elements potentially available, the United States is heavily or com pletely dependent on imports.
- The presently known proven resources of some of the rare elements will be inadequate to enable and sustain some new and important technologies, particularly electronic, optical, and magnetic materials and devices.
- Much of the California Desert has not been adequately explored for mineral resources, particularly for those rare elements of importance in advanced materials.

Rare Earths, Superconductors, Other Advanced Materials, and California Desert Minerals—A Case in Point

Yttrium and the Rare Earths. Lanthanum (La), atomic number 57, and the fourteen elements following it in the periodic table[1] are referred to collectively as the rare earth elements (RE). Yttrium (Y), atomic 39, scandium (Sc), atomic number 21, and the rare earths are remarkably similar in chemical behavior and, consequently, are generally found together in the same minerals or groups of minerals. They are used as ingredients of petroleum cracking catalysts (about half of current consumption), for television tubes, alloying elements for steel, polishing compounds, and as ingredients of specialty coatings. Hedrick (1988) has summarized the availability of the rare earths, yttrium, and scandium:

> "Rare earths (RE) are produced primarily from three ores, bastnasite ($REFCO_3$), Monazite (RE, Y, Th PO_4), and xenotime (Y, RE PO_4). Bastnasite, the world's principal source of rate earths, is mined as a primary product in the United States and as a byproduct of iron-ore mining in China. Significant quantities of rare earths are also recovered from monazite, primarily a byproduct of heavy-mineral sands mined for titanium and zirconium minerals or tin in Australia, Brazil, China, India, Malaysia, and several other countries. Smaller quantities of rare earths, especially yttrium, are obtained from the yttrium-rich mineral xenotime, recovered primarily as a byproduct of processing tinore inMalaysia, Thailand, and China, and as a byproduct of processing spent uranium leach solutions in Canada. Minor amounts of xenotime are also recovered in Australia from heavy-mineral sands. California's bastnasite mine is the only major mine in the world where rare earths are recovered as a primary product. Only very minor scandium contents have been detected in the above rare-earth minerals. Domestically, scandium is recovered as a byproduct of processing fluorite, tungsten, and uranium. Significant quantities of lanthanides, yttrium, and scandium are recoverable as byproducts from phosphate deposits in the southeastern and northwestern U.S."

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[1]Cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), and lutetium (Lu). Pm appears only as an unstable radioactive element.

The New High-Temperature Superconductors. With the announcements of a new class of superconductors, with critical temperatures above the boiling point of liquid nitrogen (77K), in 1986 and 1987, the potential importance of yttrium, lanthanum, and possibly other rare earths was suddenly increased. During 1987 and 1988, two new classes of superconductors, containing bismuth (Bi) and thallium (Ti), were discovered. There is no need to recount these recent development because the intense interest in the potential applications for these new materials prompted almost daily reports that, even two years later, have not completely abated. The question of materials availability has not received much attention, however. The Bureau of Mines has provided a qualitative evaluation of availability of yttrium, lanthanum, bismuth, and thallium (Sorrell, 1988a), using commodity data (U.S. Bureau of Mines, 1988):

> "Many of the rare earth oxides (REO) can be used to formulate superconductors of the 1 2 3 type. The yttrium compounds has received the most attention and seems to be the candidate of choice. Unfortunately yttrium oxide comprises only 0.10% of the California bastnasite ore. Total world reserves of theoretically recoverable yttrium oxide from bastnasite are estimated at 21,593 st, enough to produce only 126,000 st of the yttria superconductor. Data for Florida monazite sands are withheld to avoid disclosing company proprietary data. The United States is heavily dependent on imports for current yttria (yttria oxide) use, though not for rare-earth oxides as a group. This import dependence is likely to increase considerably as yttria-stabilized zirconia finds new uses as a high-temperature structural ceramic. World reserves of theoretically recoverable yttrium oxide from monazite are estimated at 520,390 st. Eighty percent of world reserves are in China, where rare-earth oxides are byproducts of iron ore mining.
>
> Limited availability of yttrium oxide, at least for large-volume application, seems inadequately considered as yet in research and development planning. Lanthanum oxide comprises 32% of California bastnasite, 24% of western Australian monazite, and 23% of the Chinese mixed concentrates. It would, therefore, be a more likely candidate than yttrium for large-volume use. At present, however, it appears that rare-earth superconductors will find important applications only in low-quantity uses such as integrated circuits and sensors, in which case availability will probably not be an issue.
>
> Bismuth is a byproduct derived from processing of intermediate metallurgical products, mainly from lead bullion. Availability is completely dependent on the production of primary lead.
>
> Though total production of lead bullion remained nearly constant over the 1983-1987 time period, primary production dropped from 423,000 st in 1983 to 300,000 st in 1987, the balance coming from increased recycling. The United States is heavily dependent on imports of bismuth from Mexico and several other countries. Total world reserves are estimated at 100,000 st of elemental bismuth, mostly in market economy countries. U.S. reserves are estimated at 10,000 st.
>
> It seems unlikely that lead production, which produces on average only 7 pounds of bismuth for each ton of lead, can sustain large-volume use. it is probable, therefore, that availability of bismuth will limit use of the bismuth superconductors to low-volume applications such as integrated circuits and sensors.
>
> Thallium is a byproduct of copper, zinc, and lead production, derived from flue dusts and smelting residues. The United States currently has no capacity for recovery of thallium. It depends totally on imports, 90% of which come from Western Europe. Estimated U.S. consumption in 1987 was 2 st. World reserves are estimated at only 415 st and the reserve base is 710 st. The average concentration of thallium in metal ores is only about 2 parts per million. It is apparent that only thin-film electronic and sensor applications will be feasible with the thallium superconductors."

Though the consumption of rare earths has been declining for the past several years, producers are, nevertheless, increasing their processing capacities (LaRue, 1988). There is a consensus that uses of rare earths for superconducting applications and for stabilizing zirconia ($ZrO2$), a major candidate for use as a structural ceramic, will result in a large increase in demand over the next few years.

Rare Earth Resources in the California Desert. As pointed out by Hedrick (1988), the rare earth bastnasite deposit at Mountain Pass, California is the only primary deposit in the world. The rare earths in other deposits, e.g. mineral sands and iron ore, are byproducts whose availability and costs are, of necessity, dependent on demand for the primary commodities (titanium and zirconium or iron). At present, the Mountain Pass rare earths are the principal reason the United States is nearly self-sufficient; with increased demand, however, that may not be the case and the U.S. may become dependent on foreign sources such as Australia or the Peoples Republic of China. The cost of these byproduct materials would likely increase. The Mountain Pass ore body also contains large amounts of barium and strontium carbonates and sulfates, along with thorium. All of these are important in advanced materials. The Bureau of Mines and the Geological Survey (1988) have identified yttrium deposits in the Pinto Mountains, moderate potential for rare earth oxides as well as titanium in the Cadiz Dunes area, and high potential for rare earth oxides and gold in the Clark Mountain area. These three areas are all included in the proposed wilderness areas of the California Deserts Conservation Area.

CONCLUSION

The Southern California desert is a highly mineralized area with identified resources of many commodity metals and large potential for others. the area has not been thoroughly evaluated, using up-to-date geophysical and geochemical methods. As patterns of materials use change and the rarer elements become critical for enabling new technologies, it is ever more important that these mineralized areas be thoroughly studied for occurrences of economic deposits of the precious metals, rare earths, and rare byproduct elements. Research into recovery of these materials from abandoned, presently accumulating, and future tailings could also be worthwhile.

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Chapter 5

INDUSTRIAL MINERAL EXPLORATION AND DEVELOPMENT

GEOLOGY AND GENESIS OF WHITE, HIGH PURITY LIMESTONE DEPOSITS IN THE NEW YORK MOUNTAINS, SAN BERNARDINO COUNTY, CALIFORNIA

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ABSTRACT

Very large reserves of high quality limestone are present in the New York Mountains of Eastern San Bernardino County, California. Resources are contained in Paleozoic Carbonate rocks which are overlain by Mesozoic sedimentary and volcanic rocks. The area has been affected by multiple episodes of Mesozoic deformation, intrusion and mild metamorphism.

Detailed studies demonstrate the Paleozoic rocks can be subdivided into Formations and members correlative with rocks of the Cordilleran Miogeocline. Several of the Paleozoic carbonate formations contain limestone members of economic interest. Limestones of economic interest are present in the Sultan Limestone of Devonian Age, Monte Cristo Limestone of Mississippian Age and Bird Spring Formation of Pennsylvanian Age.

Major factors influencing the genesis of the economic Carbonate deposits include depositional environment, post depositional activity, faulting, folding, uplift and erosion, and preservation through geologic time. Detailed geologic studies, bulk sampling and limited core drilling, have defined nine major deposit areas on the Pluess-Staufer (California) claims. Much of the limestone is very pure, containing >98% $CaCO_3$, and is also of moderate to high brightness (88 - >95). The limestone is suitable for all currently produced high brightness, high purity limestone products, and is identical in quality to rock currently mined on a large scale in the San Bernardino Mountains of Southern California.

Combined reserves of the 9 deposit areas in the New York Mountains comprise the largest known undeveloped high brightness, high purity limestone reserve in the Southwestern United States.

INTRODUCTION

The New York Mountains are located in eastern San Bernardino County, California (Figure 1). Several graded and dirt roads provide access to the area.

Prospecting and mining in the New York Mountains have occurred sporadically since the late 1800's. Several mines in the area have been periodically active, and lead, silver, zinc, copper and minor gold and tungsten were recovered. All metal mines in the area are currently inactive, although some claims are occasionally active. Pfizer, Inc., mines several thousand tons per year of sericite mica from a small openpit mine in the area. Numerous claims have been staked by Pluess-Staufer (CA), Inc. on extensive limestone deposits, and the area contains the largest known undeveloped high purity, high brightness limestone deposits in the Southern California Area.

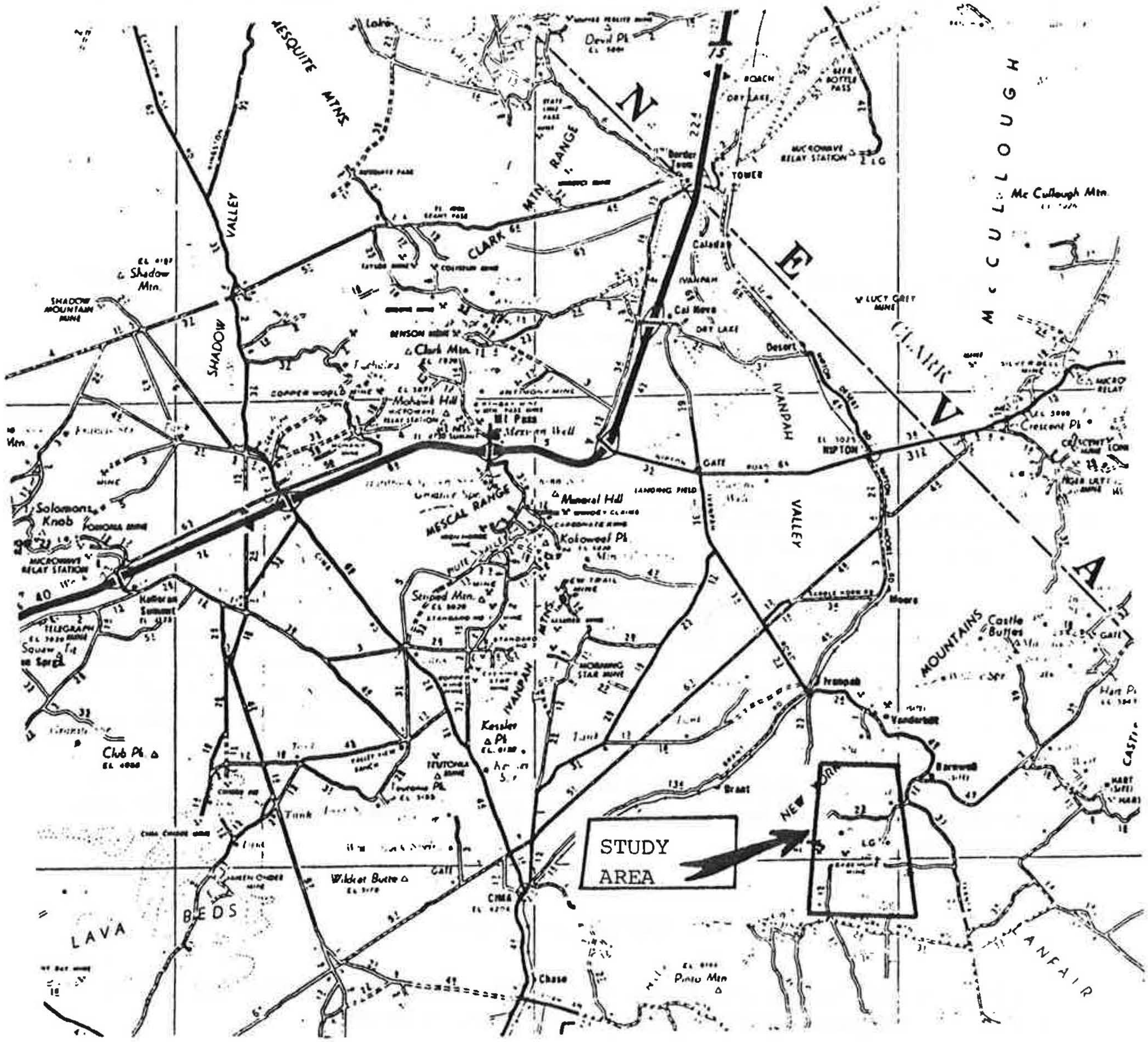


Figure 1. General index map showing area in which extensive limestone deposits occur in the New York Mountains.

PURPOSE

The purpose of this report is to summarize the geologic setting of the New York Mountains and the relationship to regional geology; to describe the carbonate rocks, their depositional environments, subsequent metamorphism and structure, and the relationship to the formation of extensive white, high purity limestone deposits of great economic potential.

PREVIOUS WORK

The geology of the New York Mountains was mapped in reconnaissance by D. F. Hewett in the 1920's, but his work was not published until 1956 (Hewett 1956). Haskell (1959) mapped the area as an M. S. thesis project and added some detail to Hewett's work. Burchfiel and Davis (1977) mapped the area in moderate detail, established the stratigraphic succession, and recognized many of the structural complexities missed by previous workers.

Limestone deposits in the New York Mountains were noted by Joseph (1985) and Evans (1986). Joseph indicated that the limestone deposits on the Pluess-Staufer claims were a significant mineral resource and were given MRZ-2b status. Geologic information indicates that significant inferred resources are present.

PRESENT WORK

This report is based on detailed geologic mapping (Brown 1986). sampling, and limited core drilling of the area. The detailed geologic mapping (scale 1:6000), of the entire area is far more detailed than any previously published maps. The present work enabled the stratigraphic sequence to be subdivided into formations, members, and subunits totaling over 40 map units, and recognized many exceedingly complex structures which were simplified, glossed over, mismapped, or simply missed by previous workers.

Detailed sampling includes over 40 blast pit bulk samples and over 250 rock samples from surface outcrops. In addition, several (6) shallow core holes were drilled in some of the more easily accessible deposit areas.

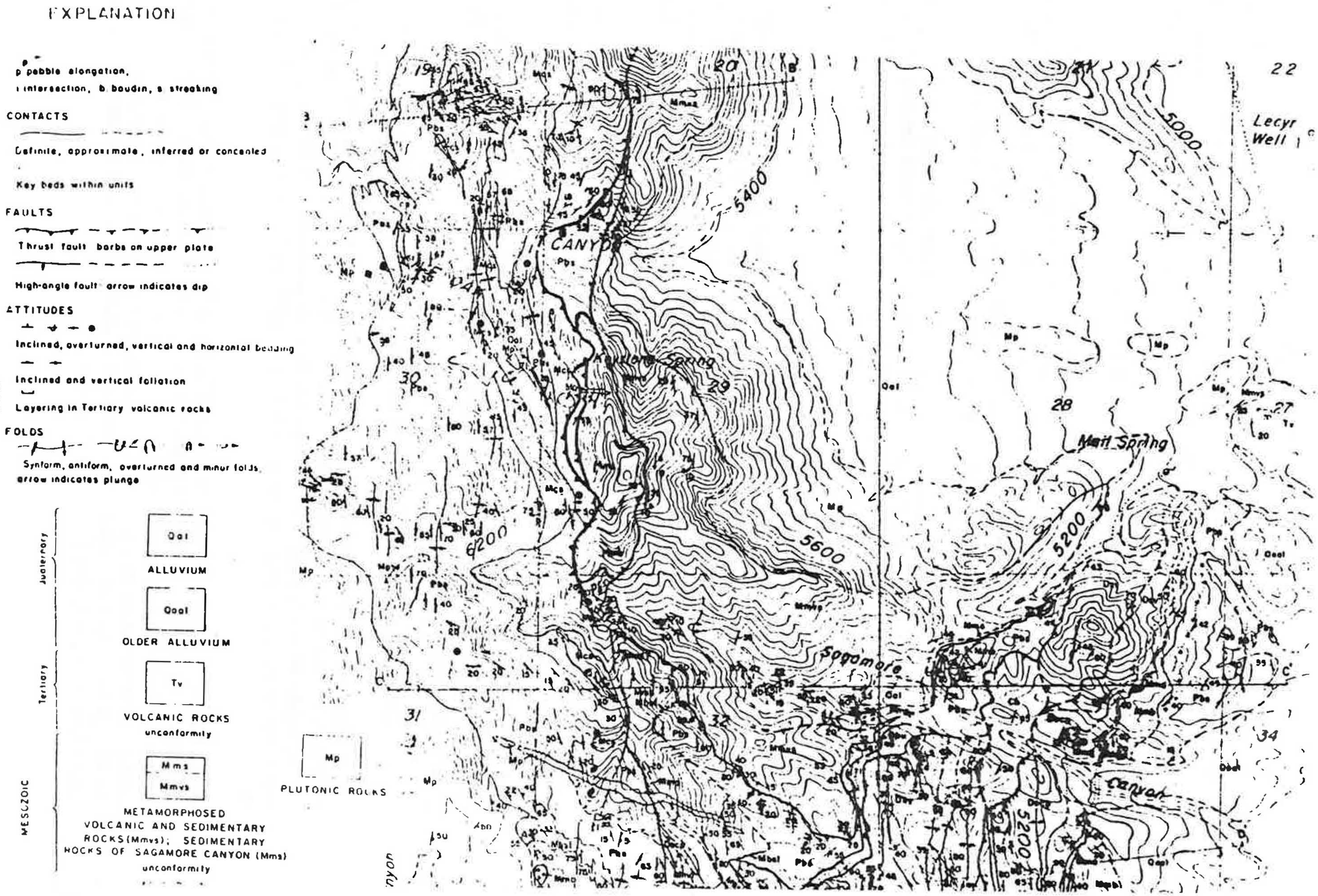
The present detailed geologic mapping and core drilling represent the most detailed and comprehensive investigation of the limestone deposits to date, and demonstrate their great economic potential.

SUMMARY OF GEOLOGIC SETTING OF THE NEW YORK MOUNTAINS

More than 6,000 feet of Paleozoic and Mesozoic rocks are present in the New York Mountains. Although recrystallized to marble, the rocks, which form a large roof pendant, can be subdivided into formations and members, and correlated with rocks typical of shallow water miogeoclinal platform deposits east of the Cordilleran Geocline (Figure 3, 4, 5, 6, Table 1).

Paleozoic formations present include Cambrian Tapeats Sandstone, Carrara Formation, Bonanza King Formation, Nopah Formation, Devonian Sultan Limestone, Mississippian Monte Cristo Limestone, and Pennsylvanian - Permian Bird Spring Formation. Calc-silicate and quartzite unconformably overlying the Bird Spring Formation is correlated with Moenkopi Formation of Triassic Age. Mesozoic metavolcanic and metasedimentary rocks unconformably overlie the Moenkopi Formation.

Figure 2A. Generalized geologic map of a portion of the New York Mountains (north part). Simplified from original map scale of 1:6000.



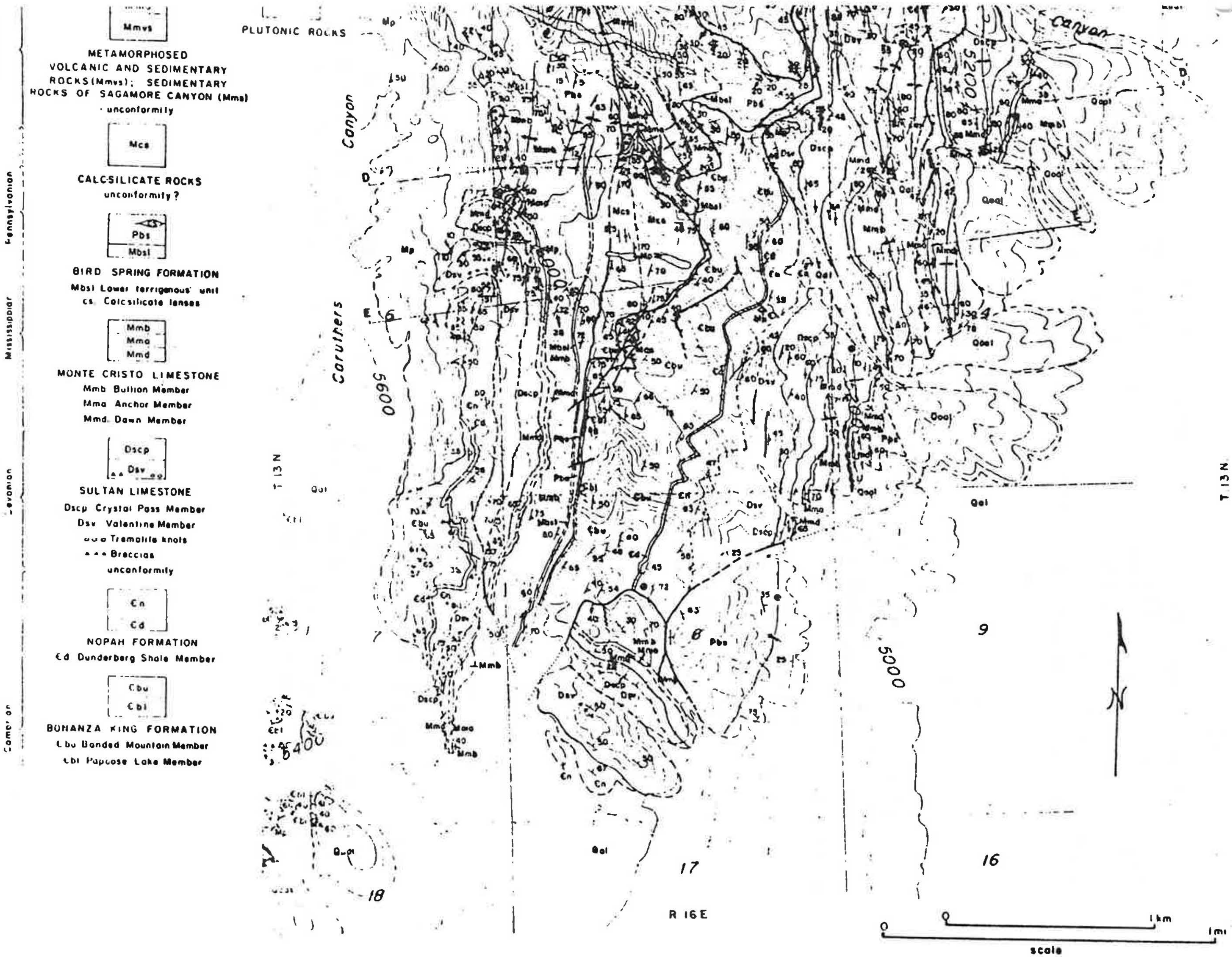


Figure 2B. Generalized geologic map continued (south portion).

Structurally, rocks in the New York Mountains are exceedingly complex. Folded Paleozoic marbles and Mesozoic Moenkopi Formation were thrust eastward over previously folded metavolcanic rocks. Complex structures belonging to as many as ten deformational events, including recumbent and upright folds, numerous low angle trusts, high angle faults of several ages, and gravity slides.

Correlation of deformational events in New York Mountains with those in adjacent ranges suggest that structures of both early and late Mesozoic age are present. Folds and thrust faults are intruded by a late Cretaceous pluton, which has yielded K-Ar ages of 71.7 my (Burchfiel and Davis 1977). On a regional scale, Mesozoic structures in the New York Mountains are part of the foreland fold and thrust belt of the Cordilleran orogeny, which can be traced more or less continuously from Canada south through the Mojave Desert region into Arizona.

ECONOMIC GEOLOGY OF LIMESTONE DEPOSITS

FORMATION OF WHITE HIGH PURITY LIMESTONE DEPOSITS

Carbonate rocks are found extensively on all continents, but high purity, high brightness (white) limestone deposits are relatively uncommon in nature because their formation is dependant on the superposition of several independent geologic processes, acting over a long period of time.

Among the processes are:

1) Deposition of originally pure limestone in high energy agitated, shallow marine environment.

2} Metamorphism and or magmatic processes to bleach and recrystallize the rock and disperse any impurities which may have been present.

3) Folding, faulting and orogenic processes to place the rocks in desirable structural settings.

4) Uplift and erosion.

5) Preservation thru geologic time.

Because all the geologic processes are required, deposits of premium quality limestone are relatively uncommon in nature, and are vastly different from common limestone.

Deposits of high brightness high purity limestone are restricted in their occurrence. Currently the major producing areas in the United States are located in Vermont, Alabama, Georgia, and Lucerne Valley, California. The Lucerne Valley area is by for the premier producing district in western North America.

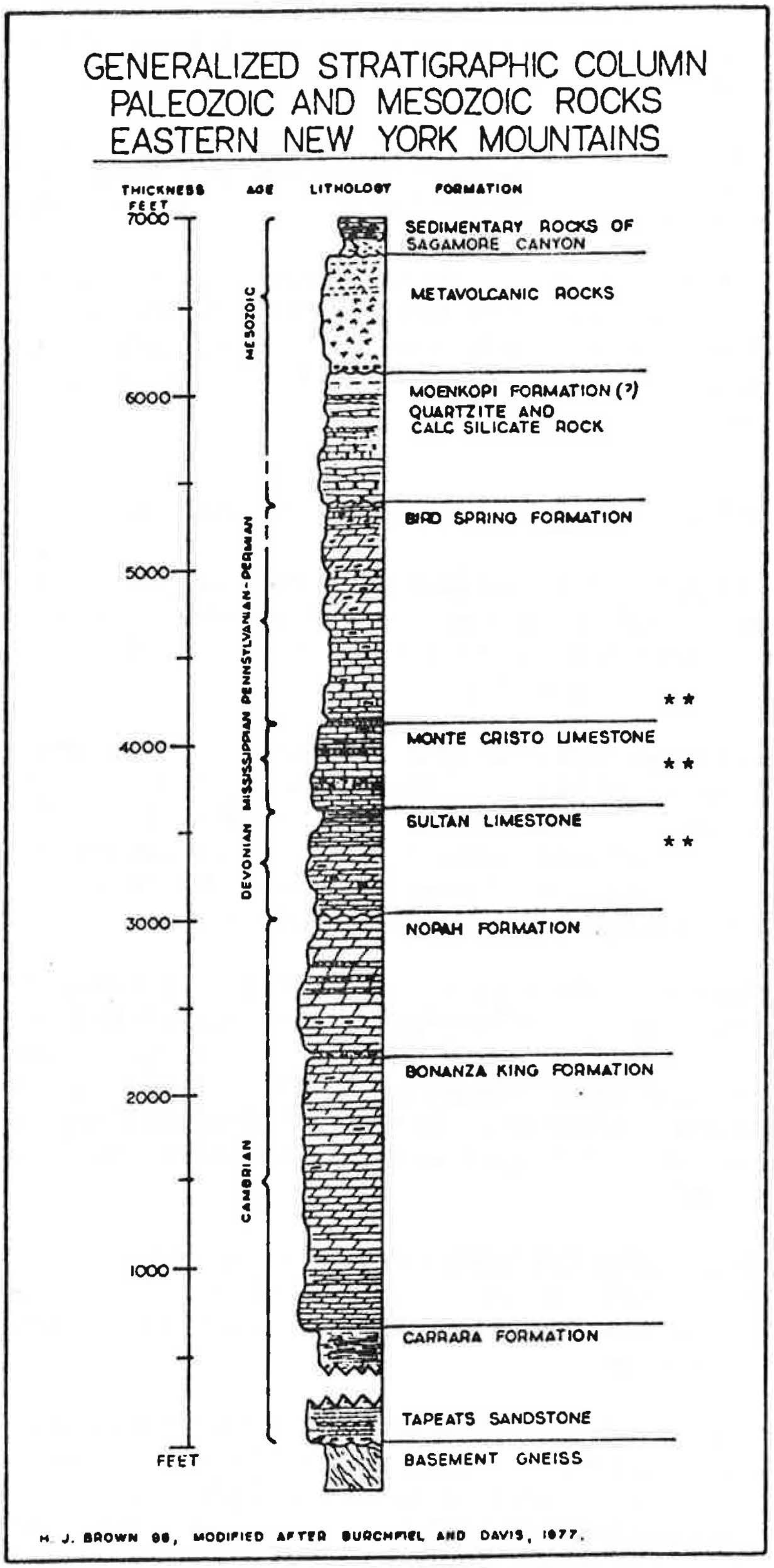


Figure 3. Generalized stratigraphic column of the eastern New York Mountains. Double asterisk (**) indicates high quality limestone.

LIMESTONE FORMATIONS OF ECONOMIC IMPORTANCE

Several high purity carbonate formations are present which have consider able potential as sources of high purity, high brightness calcium carbonate.

Formations or members of formations which have significant economic potential include Devonian Sultan Limestone, Mississippian Monte Cristo Limestone Dawn and Bullion Members, and Pennsylvanian Bird Spring Formation Lower Member (Figure 3, 4).

In the following section the geologic and economic aspects of the formations will be discussed. The formations will be described, environments of deposition, and post depositional changes discussed, and related to the formation of high purity, high brightness limestone deposits. The formations of economic interest are discussed chronologic order from oldest to youngest.

DEVONIAN SULTAN LIMESTONE CRYSTAL PASS MEMBER

The Crystal Pass Member of the Sultan Limestone is exposed in several areas. The member can be subdivided into three units, including a lower unit of thin bedded light and dark grey marble, middle white marble unit, of economic interest, and an upper unit of extensively dolomitized and stained marble.

The middle unit is composed of up to 350 feet (Tectonic thickness) of thin to medium bedded light grey to very white, pure, calcite marble. The rock is quite pure, but contains minor amounts of oxidized pyrite, and iron oxide stain on fractures and joint surfaces is common. Within the New York Mountains, the rock is metamorphosed to medium grained marble, and fossils are not present. Hewett (1956) noted that fossils are not present in Crystal Pass Member in any outcrops he had studied in the entire region.

Recrystallization, and the lack of fossils obscure the original depositional setting, however, the high purity suggests a high energy environment free from mud, clay, and silica impurities. The thin bedded nature of the rock and occasional pyrite suggest periodic lower energy and perhaps even reducing (stagnant) conditions. Metamorphism has bleached and recrystallized the rock into its present white color. Folding and thrust faults have caused several repetitions of the unit. Several outcrops form extensive dip slopes, well suited for mining, with no overburden.

The middle unit of the Crystal Pass Member of the Sultan Limestone in the New York Mountains has considerable economic potential. The Crystal Pass Member has been mined in the San Bernardino Mountains and has also been mined at Jean, Nevada, 30 mines northeast of the New York Mountains.

Numerous samples from the New York Mountains indicate much of the rock is of very high purity. Virtually all samples contain more than 98% $CaCO_3$, less than 1% $MgCO_3$ and less than 1% SiO_2 (insoluble), indicating the rock is a high purity limestone. Chemical and brightness tests on many samples including core samples indicate the rock is high purity, high brightness limestone/marble, and is suitable for all low and middle grade products. Selective mining could produce rock suitable for all high quality products.

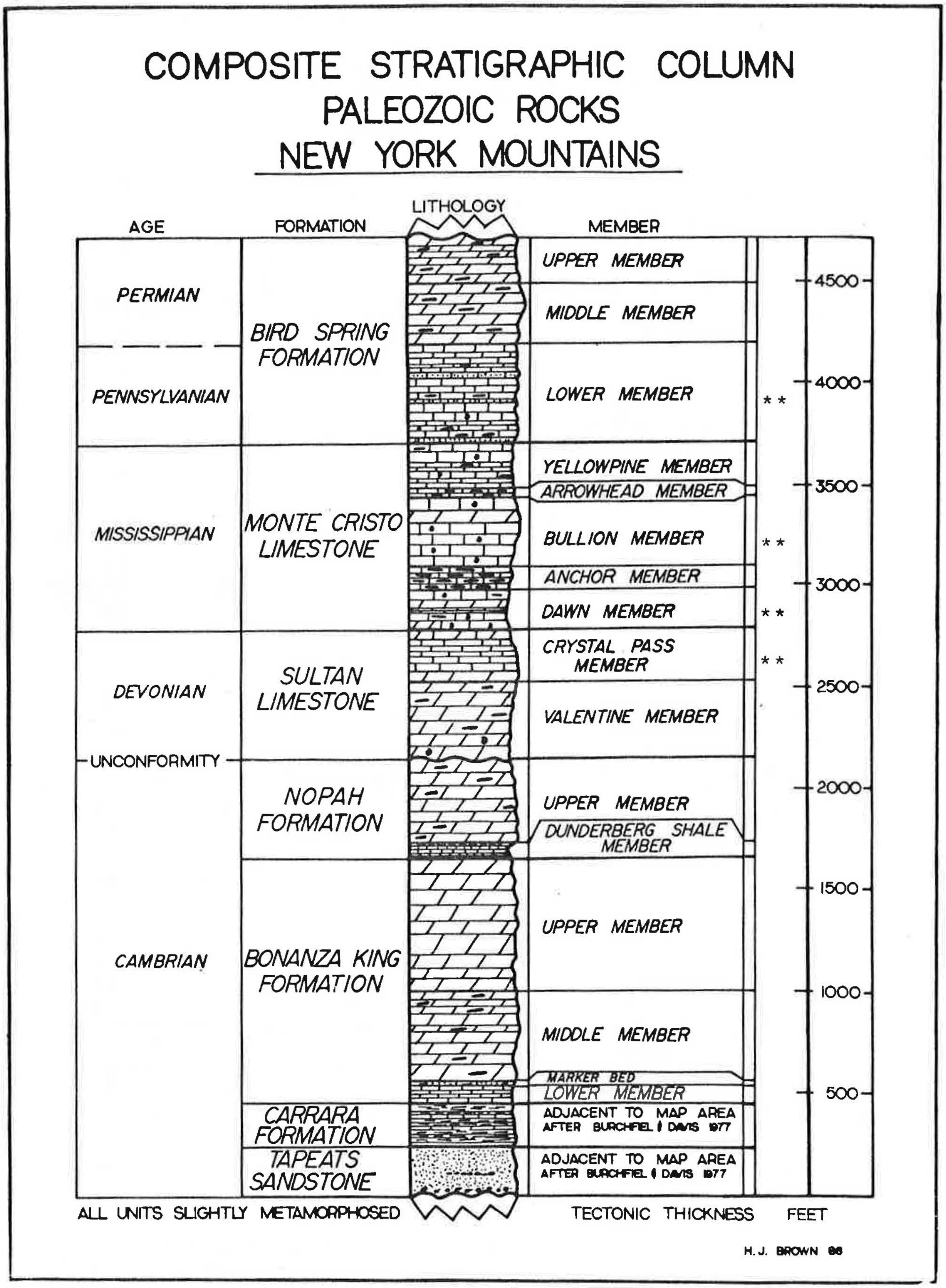


Figure 4. Stratigraphic column of Paleozoic rocks in the New York Mountains. Double asterisk (**) indicates high quality limestone.

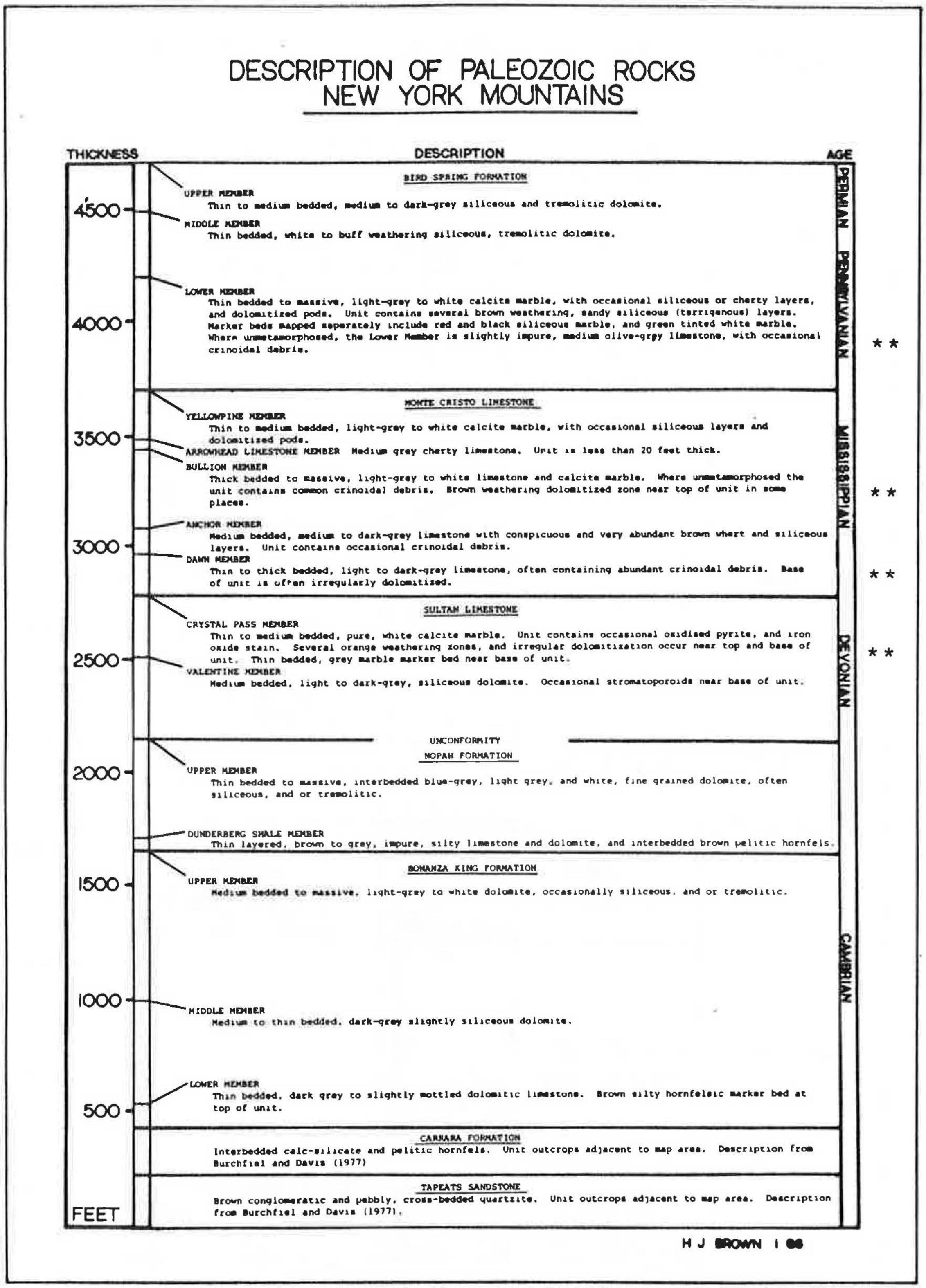


Figure 5. Description of Paleozoic rocks in the New York Mountains. Double asterisk (**) indicates high quality limestone.

MISSISSIPPIAN MONTE CRISTO LIMESTONE DAWN MEMBER

The Dawn Member of the Monte Cristo Limestone is composed of thin to thick bedded off white to dark grey limestone and dolomitized limestone. The unit is often thin bedded, streaky and silty. Secondary dolomitization is common in many places, particularly near the base of the unit, and forms a massive coarse grained, dull brownish weathering rock, devoid of original sedimentary features.

Where the rock is light grey to off white in color, the bedding is more massive, and the light grey rock contains abundant crinoidal debris, and forms bioclastic limestone. The bioclastic limestone appears to represent Type V high energy shallow marine deposition, although the thin bedded less pure parts of the member represent low energy environments.

The thick bedded pure, light grey to off white bioclastic limestone has been slightly metamorphosed and recrystallization and destruction of fossil debris is evident in the white colored rock. Folding and thrusting have repeated outcrops of the unit in several places. The light grey to white limestone in layers up to 100 feet thick, and offers considerable economic potential.

Samples collected from several locations indicate the rock contains up to 99% CaCO3 . The chemical data indicate the rock is a high calcium limestone. Brightness values range from 84 to 89. Fine grind brightness values are as high as 92. Chemical analysis and brightness values indicate the rock is suitable for high calcium limestone products, and lesser high brightness applications as well.

MISSISSIPPIAN MONTE CRISTO LIMESTONE BULLION MEMBER

The Bullion Member of the Monte Cristo Limestone is composed of thick bedded to massive, medium to coarse grained, light grey to white, often crinoidal, bioclastic limestone/ marble. Tectonic thickness is up to 350 feet. Most of USLM 87 Ridge (Keystone Canyon deposit) is composed of Bullion Member, as are several other major ridges.

Where non-metamorphosed and exposed in slide blocks in the southern New York Mountains, the rock, is medium grey bioclastic (crinoidal) limestone, typical of Type V high energy shallow marine environments. Adjacent to intrusive contacts and on USLM 87 Ridge, the rock is coarse grained translucent white calcite marble, in which fossil debris is lacking, having been destroyed by metamorphism. Further from intrusive contacts, grain size decreases, and the amount of remnant fossil debris increases, although the color of the rock is light grey to white. Folding and faulting have formed several repetitions of the unit, and erosion into dip slopes has formed several large deposits well suited for mining, with no overburden.

Many sample analysis, including thirty blast pit bulk samples, and core drilling, indicate the rock is of exceptionally high purity and brightness. Most samples contain more than 99% CaCO3, and some samples contain as much as 99.9% CaCO3 . MgCO3 and SiO2.combined in nearly all samples is less than 1%.

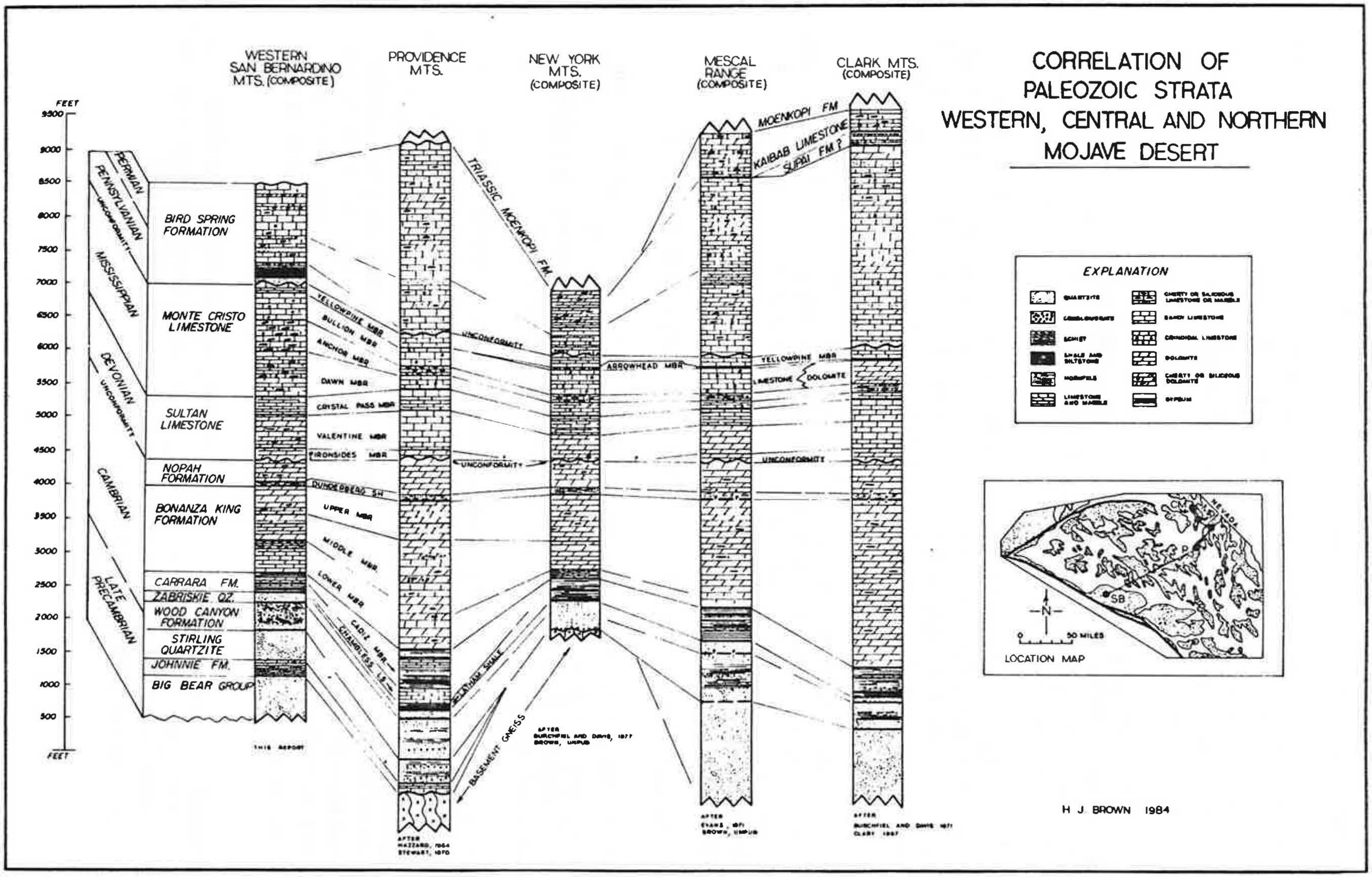


Figure 6. Correlation of Paleozoic strata from the San Bernardino Mountains to the northeastern Mojave Desert region. Note location of New York Mountains (center), after Brown (1986).

TABLE 1. CHRONOLOGY OF STRUCTURAL EVENTS NEW YORK MOUNTAINS						
		Sedimentation	Igneous	Metamorphism Mineralization	Folding	Faulting Uplift
Cenozoic	Quat.	Recent alluvium Stream terraces				Uplift
	Tertiary	Old alluvium	Volcanics			Uplift Slaughterhouse Fault Gravity slides Uplift
Mesozoic	Cret.		Pegmatite Plutonic rocks and dikes 71 my	Mineralization CaF_2, Py, Cu metamorphism Mineralization Ag, Pb, Zn, W	F_4 open folds	N70E hi angle ? TF_6 TF_5 TF_4 TF_3 High angle
	Jur.	Volcanogenic sediments			F_3 north trend upright to ot F_1, F_2 recumbent east verg	TF_2 TF_1
	Trias.	Unconformity Moenkopi Fm. Unconformity	(meta)volcanics			
Paleozoic	Penn. Perm.	Bird Spring Formation		High Grade Limestone		
	Miss.	Monte Cristo Limestone		High Grade Limestone		
	Dev	Sultan Ls. Unconformity				
	Cambrian	Nopah Fm. Bonanza King Formation Carrara Fm. Tapeats Sandstone				
PreCambrian		Unconformity Gneiss				

Table 1. Chronology of structural events and geologic history of the New York Mountains.

Brightness values range from 86 for light grey limestone to greater than 95 for whitest rock, and most fine grind brightness values are greater than 95.

Rocks of the Bullion Member of the Monte Cristo Limestone formed in Type V high energy shallow marine environments have undergone metamorphism, faulting and folding, resulting in several very large deposits of high purity, high brightness limestone/marble suitable for all high quality applications. The Bullion Member of the Monte Cristo Limestone is currently mined on a large scale in the San Bernardino Mountains as a source of high purity, high brightness calcium carbonate. Rocks of the Bullion l!ember in the New York Mountains and Keystone Canyon deposits are identical with respect to purity, brightness and quality to the deposits currently being mined.

PENNSYLVANIAN - PERMIAN BIRD SPRING FORMATION LOWER MEMBER

Rocks of the Bird Spring Formation are extensively exposed in the New York Mountains and the Keystone Canyon area. The lower part of the formation is composed of white marble, and the upper part of the formation is composed of buff white and grey siliceous dolomite.

The Lower Member is composed of several hundred feet (tectonic thickness) of thin to thick bedded white marble. The unit contains occasional grey layers, and less common sandy, siliceous and cherty horizons, and scattered dolomitized pods. Interbedded thin to thick bedded marble, cherty and siliceous layers, as well as sandy horizons indicates a variable environment of deposition, ranging from Type V high energy environments to lower energy marine, and near shore environment with terrigenous input. Outcrops of Bird Spring in adjacent ranges also display sandy horizons. Where non-metamorphosed and exposed in slide blocks, the rock contains common crinoidal debris, but is often silty, and contains pink limey silty layers, suggesting a significant quantity of sediment was deposited in lower energy marine environments in which silt was not winnowed out. Most exposures of the Bird Spring in the New York Mountains are thoroughly metamorphosed and recrystallized, and display abundant evidence of folding as well as faulting.

Chemical analysis indicates the rock is of variable but generally good quality. $CaCO_3$ ranges from 88% to more than 99%. $MgCO_3$ is less than 3%, and acid insolubles show some variation, ranging from less than 0.5% to as much as 9%. Brightness values, range from 88 to greater than 95 for brilliant white translucent marble.

Although up to 30% of the rock of this unit is not suitable for high purity high brightness applications, selective mining could produce high purity, high brightness calcium carbonate suitable for all high quality applications; and, therefore, the rock is considered to have high economic potential.

ECONOMIC GEOLOGY OF INDIVIDUAL DEPOSITS

Numerous individual limestone deposits are present in the area. Figure 7 is a reference map showing numbered deposits. The combined reserves indicate that the New York Mountains contain the largest easily accessible undeveloped reserves of high purity, high brightness limestone in the southwestern United States.

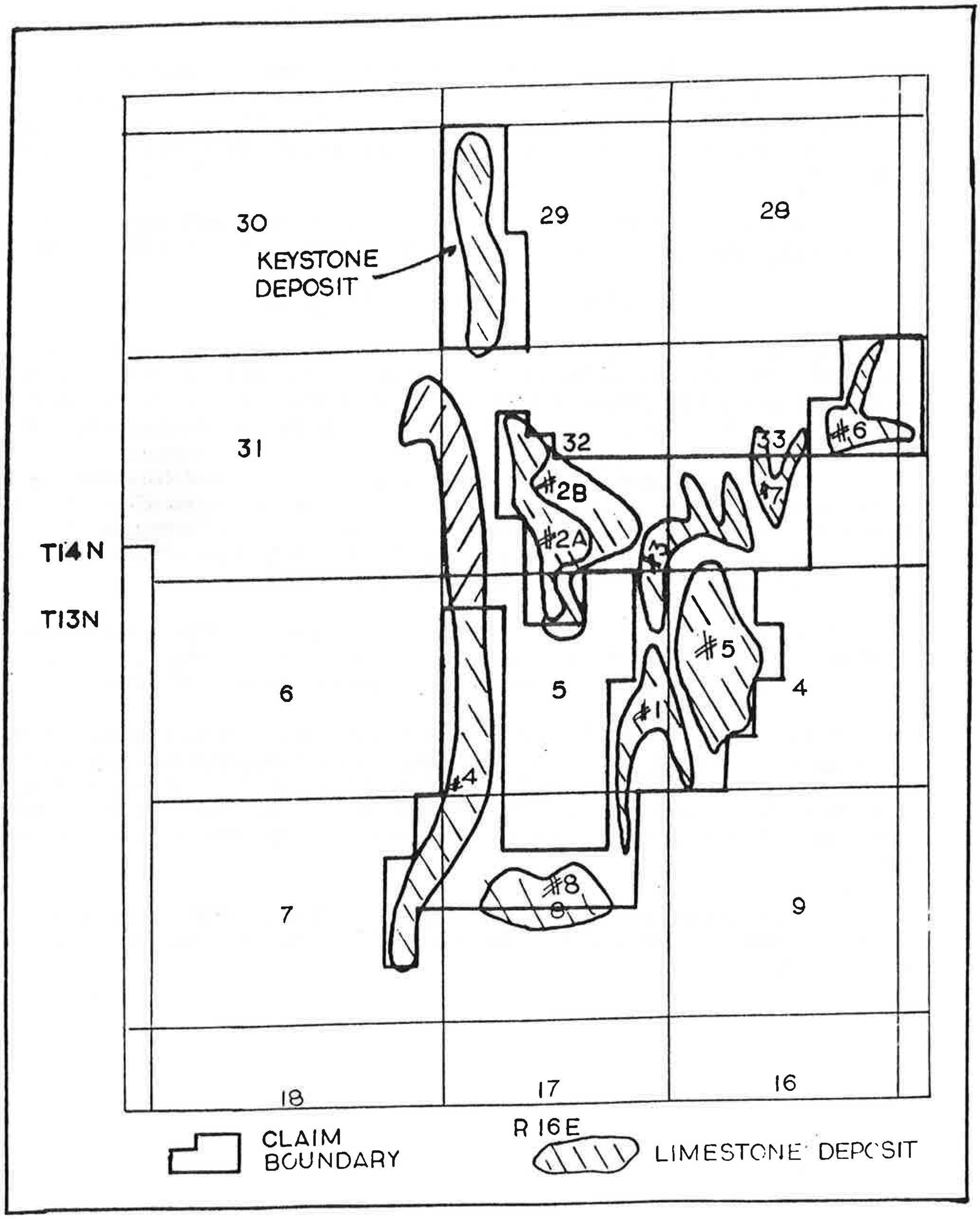


Figure 7. Map of Pluess-Staufer (California) Inc. limestone claims showing individual deposits.

Limestone deposits in the New York Mountains have been known for many years (Logan 1947). During 1981 Pluess-Staufer located numerous mining claims in the area, on the limestone deposits. Subsequent work has defined 9 deposit areas.

COMBINED RESERVES ALL AREAS

As noted previously, the New York Mountains contain very large reserves of high quality limestone. Based on detailed geologic studies, drilling and bulk sampling, much of the rock is of exceedingly high purity (>98% $CaCO_3$), and the vast majority is of high brightness (86-95). Rock of this quality is identical to that currently being mined and processed on a large scale in the San Bernardino Mountains and Lucerne Valley area of Southern California.

The New York Mountains deposits combined, form the largest, easily accessible, undeveloped, high purity, high brightness limestone deposits in the Southwestern United States.

SUMMARY AND CONCLUSIONS

Very large reserves of high quality limestone are present in the New York Mountains of eastern San Bernardino County, California. Resources are contained in Paleozoic carbonate rocks which are overlain by Mesozoic sedimentary and volcanic rocks. The area has been affected by multiple episodes of Mesozoic deformation, intrusion and mild metamorphism.

Detailed studies demonstrate the Paleozoic rocks can be subdivided into formations and members correlative with rocks of the Cordilleran miogeocline. Several of the Paleozoic carbonate formations contain limestone members of economic interest. Limestones of economic interest are present in the Sultan Limestone of Devonian age, Monte Cristo Limestone of Mississippian age and Bird Spring Formation of Pennsylvanian age.

Major factors influencing the genesis of the economic carbonate deposits include depositional environment, post depositional processes including metamorphism, intrusive activity, faulting, folding, uplift and erosion, and preservation through geologic time.

Detailed geologic studies, bulk sampling, and limited core drilling, have defined nine major deposit areas on the Pluess-Staufer (California) claims. Much of the limestone is very pure, containing >98% $CaCO_3$, and of high brightness (88-95). The limestone is suitable for all currently produced high brightness, high purity limestone products, and is identical in quality to rock currently mined on a large scale in the San Bernardino Mountains of Southern California.

Combined reserves of the 9 deposit areas in the New York Mountains comprise the largest known undeveloped high brightness, high purity limestone reserve in the Southwestern United States.

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THE HUNTER MT. WOLLASTONITE DEPOSIT: AN IMMOVEABLE OBJECT TRAPPED BY IRRESPONSIBLE FORCES

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INTRODUCTION

Wollastonite is a naturally occurring crystalline calcium metasilicate which was named after the English chemist William H. Wollaston. It is a contact metamorphic mineral which frequently occurs in skarns or tactites formed in calcareous rocks intruded by granitic rocks. Nevertheless, large deposits of high-purity wollastonite which are economically viable are rare.

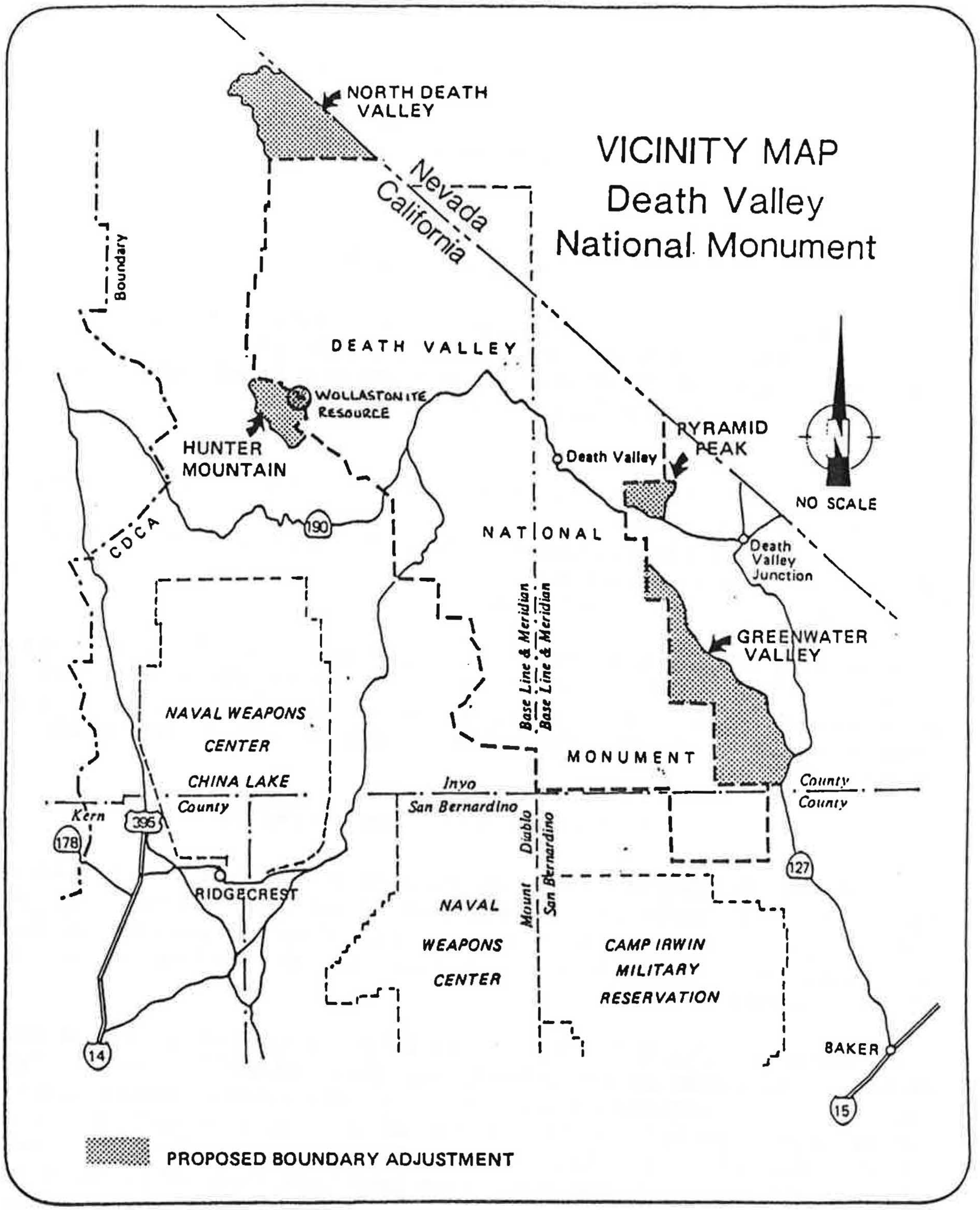
This paper provides a brief introduction to the geology and markets for wollastonite and garnet products which could be produced from the Hunter Mt. deposits. Although much of the mineral resource lies within Death Valley National Monument, the west end of the Hunter Mt. wollastonite deposit, which is outside of the Monument, appears to contain many millions of tons of high-purity, iron-free wollastonite.

However, the West End Deposit has now been included in an area being considered for inclusion into Death Valley National Monument, despite classification as a multiple use area in the California Desert Conservation Plan. Management of the West End deposit by the National Park Service will effectively block the exploration and development of this unique mineral deposit.

LOCATION AND LAND STATUS

The Hunter Mountain wollastonite deposit is on the west side of the Panamint Range both adjacent to and within the northwestern part of Death Valley National Monument. The deposit is about 30 miles east of Lone Pine, California in portions of sections 21, 25, 26, 27, and 28, T. 15 S., R. 41 E., and sec. 30, T. 15 S., R. 42 E. Mt. Diablo Base Line and Meridian, Inyo County, California.

The deposit is reached from Olancha, California by following California State Route 190 eastward about 31 miles to the Saline Valley road. Turn north (left) onto the Saline Valley road and follow it northward 15 miles to its junction with the road to Hunter Mountain. Turn eastward (right) onto the Hunter Mountain road which is well-maintained but less traveled than the Saline Valley road. Follow the Hunter Mountain road about 7 miles to the junction with the road leading northeastward (right) into Death Valley National Monument. From the junction it is about 5 miles to the east end of the Hunter Mountain wollastonite deposit. The road to the northwest (left) continues another 5 miles to the west end of the Hunter Mountain wollastonite deposit. Though rough and steep in a few places this road is passable to two wheel drive vehicles. Inyo County maintains the road to the junction of the roads leading to the east and west ends of the wollastonite. Therefore, only the final 5 miles of road to the west end of the deposit are not maintained by Inyo County.


VICINITY MAP
Death Valley
National Monument
NORTH DEATH VALLEY
Nevada
California
Boundary
DEATH VALLEY
WOLLASTONITE RESOURCE
HUNTER MOUNTAIN
PYRAMID PEAK
Death Valley
NO SCALE
CDCA
190
NATIONAL
Death Valley Junction
Base Line & Meridian
GREENWATER VALLEY
NAVAL WEAPONS CENTER CHINA LAKE
MONUMENT
Inyo
County
San Bernardino
County
Kern
County
395
178
Diablo
Mount
San Bernardino
127
RIDGECREST
NAVAL WEAPONS CENTER
CAMP IRWIN MILITARY RESERVATION
BAKER
14
15
PROPOSED BOUNDARY ADJUSTMENT

When the East End Deposit was being operated by American NonMetallics the wollastonite was hauled in 10 wheel dump trucks to a transfer point at the junction. The 10 wheel dump trucks discharged their loads at a stockpile where the wollastonite was stored until loaded into highway-type 18 wheel tractor trailer units which hauled the wollastonite to the grinding plant. Between 2000 and 3000 tons of wollastonite were handled this way.

When Joe Ostrenger staked the original 47 claims in the J. 0. and Calmet claim groups between 1957 and 1960, deposits of locatable minerals such as wollastonite on Federal Lands both outside and inside Death Valley National Monument could be acquired by staking claims. Mining was also permitted in Death Valley National Monument and five other National Parklands.

Congress passed Senate Bill 2371 (Public Law 94-429) which became law on September 28, 1976. The law provided for the regulation of mining activities within Death Valley National Monument and 5 other Parklands. The Federal Land policy and Management Act of 1976 (Public Law 94-579) became law on October 21, 1976. It provided for the regulation of mining activities on Federal Lands and also the review of lands determined to have wilderness characteristics for possible inclusion in the wilderness system. The immediate effect of these two public laws was to stop all exploration and development activity on the claims within the Death Valley National Monument, and severely restrict these same activities on the claims outside the monument.

Section 8 of Public Law 94-429 required that all mining claims in Death Valley National Monument be recorded with the Secretary of the Interior within one year after the effective date of the act. Mr. Ostrenger refused to record the claims with the National Park Service contending that recordation with the Bureau of Land Management satisfied the requirement. As a result, the Park Service ruled the claims covering the east end of the wollastonite deposit within Death Valley National Monument invalid because of nonrecordation.

The claims covering the West End Deposit were included in the 25 million acre California Desert Conservation Area created under section 601 of the Federal Land policy and Management Act of 1976. The Secretary of the Interior was directed to "prepare and implement a comprehensive, long-range plan for the management, use, development, and protection of the public lands within the California Desert Conservation Area". The West End Deposit was originally included in Wilderness Study Area 123 and subject to the rules "Regulating Exploration and Mining-Wilderness Review Program" which would limit unregulated mineral uses to the same "manner and degree" as on October 21, 1976. It would have severely restricted any new exploration and development activities on mining claims even though a valid mineral discovery had been made prior to October 21, 1976.

Fortunately,that portion of Wilderness Study Area 123 which covered the west end of the wollastonite deposit has been reevaluated as non-suitable for wilderness and placed in the class L multiple use category. This has allowed continued exploration and mining activity.

GEOLOGY

The wollastonite deposit which is 300 to over a 1000 feet wide extends from the West End Deposit a distance of about 5 miles to the East End Deposit. The wollastonite appears to have formed along a favorable stratigraphic horizon within a section of Paleozoic sediments intruded by the Hunter Mountain quartz monzonite. The unmetamorphosed equivalent host rock appears to have been Permian or Devonian age cherty-limestones.

The wollastonite is a light grayish-white to nearly white color. Individual crystals are less than a millimeter in length. Only rarely can the characteristic tabular crystals be seen in hand specimens. Specimens of wollastonite are difficult to break because of the intergrown tabular crystals.

Associated with the wollastonite are bands of gray to grayish-brown colored microcrystalline quartz. On weathered surfaces the quartz stands out in relief as dark brown ridges which appear to be the metamorphosed equivalent of chert lenses in the unmetamorphosed limestone. The bands of quartz appear to reflect the bedding in the original limestone.

Calcite occurs in blue-colored coarsely crystalline masses in elongate lenses, veinlets, and breccia zones within the wollastonite. On weathered surfaces it is difficult to differentiate between the wollastonite and marble. However, on freshly-broken surfaces the minerals are easily identified.

Diopside appears to be intergrown with the wollastonite. X-ray diffractograms confirm that diopside is associated with the wollastonite, however, it is not possible to determine the percentage present. Based on the MgO content of the wollastonite from the east end deposit, Don Clark estimated it contained about 20% diopside. Because the iron content of the diopside is so low it is a white color and in hand specimen virtually is indistinguishable from the wollastonite.

Garnet occurs in the contact zone adjacent to the Hunter Mountain quartz monzonite. It does not appear to occur in the wollastonite, probably because of the nearly iron-free geochemical environment which existed when the wollastonite formed. The area of greatest immediate potential is an outcropping on the J.O. 11 claim locally referred to as "garnet hill". The outcrop is capped by igneous rock and rests on altered limestone. The garnet horizon is mainly massive brown almandite with some green crystalline garnet. The exposure covers an area about 300 feet on a side and has a average estimated thickness of 10 feet.

In measured sections across the wollastonite in an attempt to estimate the wollastonite content, it appears that the West End Deposit contains about 20% quartz and 10% calcite, with the remainder being wollastonite and diopside. Assuming that the mineralogical composition of the East End and West End Deposits are roughly comparable then the deposit contains 20% diopside and 50% wollastonite. This is comparable to the grade of the deposit being mined by NYCO at Willsboro, New York. Beneficiation studies done on the East End of the Hunter Mountain wollastonite deposit indicated a high-brightness, low-iron wollastonite product which meets the specifications established by the British Ceramics Society can be produced from the deposit.

As mapped by Don Clark, the wollastonite outcrop at the west end deposit is about 1600 feet long by 1000 feet wide. The exploration project completed for Nor-Con determined that a resource of as much as 18 million tons of 60% wollastonite was available. For comparison the NYCO operation at Willsboro, New York produced an estimated 100,000 tons of processed wollastonite in 1987. The West End deposit could easily support a sizeable wollastonite processing facility.

In summary, the West End Deposit appears to be a large deposit of wollastonite capable of producing a high-purity wollastonite product with a high brightness and a low iron content. Wollastonite demand is expected to continue its rapid growth over the next decade. In addition, a source of wollastonite in California for the production of both natural and surface treated products consumed in the western United States would enjoy a substantial freight advantage over the competitive products supplied by NYCO and R. T. Vanderbilt from operations in New York State. And finally, wollastonite from the deposit would have large export markets in Japan, Korea, Taiwan and other industrializing countries surrounding the Pacific Basin.

DEVELOPMENT OF THE WOLLASTONITE INDUSTRY

Wollastonite has been used as an industrial mineral only since 1933. The first reported production was from a deposit near Randsburg, California for use in the production of mineral or rock wool for insulation. The deposit produced a small quantity of wollastonite between 1933 and 1934 and again between 1938 and 1941.

The wollastonite deposit at Willsboro, New York was discovered about 1940. Titanium Alloy Manufacturing Company began production from the deposit in 1943. After the ownership of the deposit had changed three times, Cabot Corporation bought the deposit in 1951, constructed new facilities, and in 1953 began producing beneficiated wollastonite for use as a shrinkage control additive in ceramic tiles. By 1958 production had increased to 20,000 tons per year.

In 1969 after increasing production to 27,500 tons per year and capacity to 30,000 tons per year Cabot Corporation sold the entire operation to Interpace Corporation. The capacity of the operation was increased to 70,000 tons per year in 1975 and another expansion program in 1977 increased capacity an additional 30 percent. Production in 1977 was 60,000 tons.

In 1979 Interpace Corporation sold the operation to Processed Minerals, Inc. a wholly owned U. S. subsidiary of Canadian Pacific Investments Ltd. of Montreal who changed the name of the operation to NYCO. Production capacity at the Willsboro operation is currently estimated at 100,000 tons per year. The U.S. Bureau of Mines does not publish production statistics in order to avoid disclosure of proprietary data.

R. T. Vanderbilt Company Inc. began production from a wollastonite deposit near its Gouverneur, New York talc operation in 1978. Production capacity at the operation is estimated at 25,000 tons per year.

Pfizer Incorporated mines wollastonite on an intermittent basis from deposits in the Little and Big Maria mountains near Blythe, California and near Coyote Dry lake northeast of Barstow, California.

American Non-metallics in 1963 and 1964 mined several thousand tons of wollastonite near Ubehebe Peak in the Panamint range in Inyo County, California. The deposit, which now is known as the Hunter Mountain deposit, appears to be the largest known deposit of high purity wollastonite in California if not the entire United States.

At Hunter Mountain the wollastonite occurs as long acicular crystals having an aspect ratio (length to diameter ratio) of 7-8 to 1 and a brilliant white color. These two properties are essential to many of its industrial uses. Other properties important in industrial use are solubility in water (0.0095 gm/100 ml at 25° C), low coefficient of thermal expansion, alkalinity, chemical activity (inert), and high brightness (99% pure, -325 mesh has a General Electric reflectance rating of 92 to 96%).

The wollastonite content of currently productive deposits is variable. There appears to be no minimum cut off grade because by or coproducts such as limestone and garnet, which usually are associated with the wollastonite, often contribute a substantial amount of revenue to the operations. However, the material presently being mined usually contains 50 to 65% wollastonite, though deposits containing as little as 30% wollastonite have been mined.

The Fox Knoll mine at Willsboro, New York was the largest wollastonite operation in the world. This was also the only major deposit in the world mined underground. The other deposits are mined by open-pit mining methods. In 1982 NYCO began development of their open pit mine at Lewis, New York 14 miles west of their Willsboro mill site. The mining costs at Fox Knoll were increasing rapidly and the deposit was approaching depletion.

Wollastonite ore produced by NYCO is crushed and ground before being run through magnetic separators to remove the garnet, diopside, and other ferromagnesian minerals. The quartz and calcite are generally removed after further grinding by flotation. Further treatment is used to produce grades with particle sizes ranging from 20 to 325 mesh. Attrition milling is used to increase the particle aspect-ratio for fibrous grades. All grinding must be done in pebble mills to prevent contamination from iron.

The United States is the world is largest producer of wollastonite followed by Finland and Turkey. Other wollastonite producers are China, India, Kenya, and Mexico. World production more than doubled during the eight year period from 1970 to 1977 inclusive. China is a relatively new producer of wollastonite entering the world market in 1986.

The only two companies known to have produced wollastonite in the United States during 1987 are NYCO and the R. T. Vanderbilt Company. Depending on grade, wollastonite products sell for $80200 per ton. Surface treated grades of wollastonite sell for $340 to as much as $750 per ton.

Demand for wollastonite is currently limited by price and availability. Natural wollastonite faces competition from synthetic wollastonite for certain uses common to both products. Even though synthetic wollastonites resemble natural wollastonite, the synthetics lack an acicular crystal structure which is required for many important end uses.

Ceramics, paint, and refractories still remain the largest end uses of wollastonite. Wollastonite can partially or wholly replace asbestos in cements, flooring tiles, plastics, roofing, insulation and paper which are typical of short fiber asbestos applications. Wollastonite has also made a significant penetration into the fibered aluminum coating, and fiberglass markets.

It appears that the growth of demand for wollastonite will continue as many of the traditional asbestos markets are penetrated. The use of wollastonite as a filler in plastics is increasing rapidly. As a result of problems experienced with both asbestos and fibrous talc, as much as 20% of the plastics filler market could eventually be supplied by wollastonite.

To capture a larger share of the plastic filler market NYCO in 1978 began marketing surface treated grades of wollastonite. Whereas the untreated wollastonite product wells for about $0.04 to SO.10 per pound ($80 200 per ton) the surface treated product sells for about $0. 17 - .38 per pound (S340 - 750 per ton).

By treating the wollastonite with organic coupling agents or surface modifiers which react with both the plastic resin and the wollastonite filler a strong bond is formed between the two compounds. This leads to either improved performance, which is the objective in engineering plastics, or a reduction in the amount of plastic resin used. The use of coupling agents offset the deterioration in performance which usually limits higher percentages of fillers in the plastics.

Silanes are the coupling agents usually used in the surface modifiers for natural silicate minerals such as wollastonite. One major supplier believes that surface treated wollastonite will gradually replace the use of expensive glass fibers in many engineering plastic applications.

Wollastonite demand is expected to continue its rapid growth over the next decade. A source of both surface treated and untreated wollastonite in California would enjoy a substantial cost advantage over the products sold by NYCO at Willsboro and R. T. Vanderbilt at Gouverneur, New York. The large deposit of high purity wollastonite at Hunter Mountain, California could be a source of wollastonite for the western United States markets as well as the Pacific Rim countries.

HISTORY OF THE HUNTER MT. DEPOSIT

The Hunter Mountain wollastonite deposit was discovered by Joe Ostrenger a prospector and small mine operator who was during the 1950's attempting to develop several small contact metasomatic copper deposits near Hunter Mountain. While prospecting, Mr. Ostrenger discovered several extensive outcrops of a bluish-white mineral which resembled marble but was heavier, harder, and more difficult to break. Subsequent analytical work determined that the mineral was wollastonite. And, between 1957 and 1960 Mr. Ostrenger located 47 lode claims which covered all of the wollastonite outcrops.

In the early 1960's Gladding-McBean the manufacturer of Franciscan Ware formed a subsidiary known as American NonMetallics to mine the east end of the deposit in Death Valley National Monument. American Non-Metallics produced two grades of processed wollastonite: a minus 200 mesh ceramic grade marketed as Cart-O-Lite and a minus 325 mesh grade marketed as Anomite. Fol lowing the merger of Gladding-McBean into Interpace Corporation mining operations at the east end deposit were suspended. The reasons Interpace Corporation shutdown the American-Non-Metallics operation are a matter of conjecture. However, at the time Interpace Corporation was the only supplier of processed wollastonite in the United States. Therefore, the possibility of an antitrust suit for monopolizing the wollastonite market or other competitive considerations may have prompted the closure.

During the mid 1960's Union Carbide Corporation, which operated an asbestos mine and milling facility at King City, California, considered adding processed wollastonite to their existing asbestos product lines. After a comprehensive geological investigation of the property, bulk samples were shipped to the Union Carbide Minerals Research facility at Sterling Forest, New York for metallurgical testing. Even though an excellent high-purity wollastonite product with high brightness could be produced, subsequent marketing studies suggested that wollastonite would make a significant penetration into many of their existing short fiber asbestos markets. Consequently, the wollastonite project was dropped. Wollastonite has since displaced asbestos from many of its short-fiber applications.

In 1974 Western American Minerals approved plans to begin production at the Hunter Mountain deposit. This operation, apparently, did not get much beyond the planning stage. Sometime later Mr. Ostrenger had Moore & Taber, a Geological and Engineering Consulting Firm in Anaheim, California prepare a promotional brochure entitled "California Wollastonite" in an attempt to promote the sale of the deposit. Don Clark a geologist for Moore & Taber mapped the deposit and prepared the report.

In 1985 the J.O. claim group was leased to Nor-Con a Canadian based exploration company. Nor-Con had Moore & Tabor complete a small exploration drilling and sampling program. The drilling blocked out a wollastonite resource containing about 18 million tons of material with an average wollastonite content of 60%. This is comparable to most commercial deposits.

Subsequently, NYCO, a division of Processed Minerals Inc. completed a more extensive evaluation of the property. The results of this investigation were favorable, but the project was not continued because of concerns over the possible surface reclamation and environmental restrictions which might be imposed by the passage of the Cranston Bill S-7 which was pending in Congress though not passed. The present proposal to place Hunter Mt. into Death Valley National Monument would also prevent the development of this unique mineral resource.

WOLLASTONITE AND GARNET MARKET OVERVIEW

It is difficult to accurately quantify world production and consumption of wollastonite. Presently the base production in the United States is between 110,000 and 130,000 tons annually. World production may exceed 200,000 tons.

Consumption of wollastonite depends heavily on its availability at a competitive price. Wollastonite products in the western United States and circum-Pacific regions is either prohibitively expensive or of poor quality. As a result, the markets for wollastonite in these areas are not well developed.

The highest value applications for wollastonite are as functional fillers in plastics. Use of any specific mineral product in large part is determined by the final application. Where cost is important the least expensive filler, generally ground calcium carbonate, is chosen. But, in applications where the finished product must meet stringent mechanical specifications, higher cost functional fillers like wollastonite are used.

Consumption of wollastonite in the western U.S. plastic filler markets was estimated to be 2000 - 3000 tons in 1984. It should be possible to build a market of as much as 20,000 tons per year of all grades of wollastonite from Hunter Mountain.

The markets for wollastonite in paints and ceramics probably offer the greatest near term opportunity. In paint applications the calcite content of the product may not be a problem. Most important will be the brightness, particle shape and oil absorption.

The paint market is large and sales have recovered strongly since 1982. The rate of future growth however, is expected to be about 3.7% per year. The paint industry is a mature cyclical market, and growth in consumption of mineral fillers is largely due to increases in the filler loading to displace the higher cost resin raw materials.

Presently consumption in this market in the western United States is about 5000 tons of wollastonite annually. A deposit in California could remain competitive on price yet take advantage of the lower freight costs to get the product to market. In addition the wollastonite may be competitive with the ground calcium carbonate producers in California. In 1982 about 100,000 tons of ground calcium carbonate products were consumed as fillers and pigments in the 11 western states. According to C.H. Kline less than 1000 tons of wollastonite was consumed in 1983 in the same market area. But, based on consumption patterns in the rest of the United States sales of wollastonite in this market can be expected to grow to nearly 10,000 tons annually if wollastonite was available at competitive price.

The ceramics markets, based on present patterns of consumption will provide the greatest volume of sales. In many respects it will also be the most difficult market to serve. The acicular shape of the product remains important, but the fired ceramic color is critical. Trace impurities can dramatically affect product acceptance.

The consumption of ceramic grades of wollastonite in the western United States in 1983 was probably under 3000 tons. The high transportation costs from the deposits in the northeastern U.S. cancel the savings over competitive materials wollastonite can provide. Advances in technology in ceramics may provide new markets for high purity wollastonite in the future. For wollastonite from Hunter Mountain the market could grow to as much as 10,000 tons in the western and midwestern United States.

There appears to be sufficient demand in the United States to justify investment in a deposit in California. Additional markets may be open in Japan and Asia. Currently, Japan's reported consumption of wollastonite is about 2000 tons annually from NYCO and an equivalent amount from India. These products are probably functional fillers for plastics.

TABLE 1: World Production of Natural Wollastonite by Country

1979 -1983

	1979	1980	1981	1982	1983
Finland	10576	8782	13690	15000	20000e
India	3800	5800	15500	20555	20000e
Kenya	-	-	-	50	-
Mexico	11892	14400	14602	14000e	14000e
USA	74000	76000	80000	100000e	125000e
Total	100268	104982	123842	149000e	179000e
USA % of change	+6%	+3%	+5%	+20%	+25%

e: estimate
-: data not available

Source: USBM Yearbook, Institute of Geologic Sciences, Industrial Minerals Magazine, Roskill Information Services, Charles Kline & Company

Unlike wollastonite there is good current data available on the markets for garnet. It is interesting to note that the production and consumption of garnet in the U.S. has apparently increased dramatically since 1986. Much of the growth appears to be the result of the increasingly stringent regulations concerning silica in competitive abrasive materials, particularly silica sand. Slags used as abrasives are also facing additional regulation because of their base metal content and the problems associated with dust caused by the breakdown of the abrasives.

TABLE 2: U.S. Garnet Production - Consumption

	1984	1985	1986	1987 e
Production	29,647	36,727	32,296	41,900
Sales	27,672	30,634	31,856	43,700
Imports			400	3,000
Exports	3,400	3,200	5,500	5,500
U.S. Consumption	24,272	27,434	26,756	41,200

Source: USBM
e: estimated, import source 100% Australian

RESOURCE MANAGEMENT ON PUBLIC LANDS

There is considerable debate on the proper use of natural resources on public lands. Unfortunately most of these lands and resources are located in the western U.S., while the debate takes place in Washington D. C. Many of the western states have more than half, and in some cases as much as 90% of the lands within their borders held and managed by the Federal Government.

Between 1964 and 1984 Congress passed 72 laws creating 455 wilderness areas designating nearly 90 million acres of public land as a part of the wilderness system. To date there has been no systematic appraisal of the cost of these land withdrawals from multiple use management. No other nation 1 know of, has committed such a large portion of its natural resources to such an unproductive use, with so little factual debate.

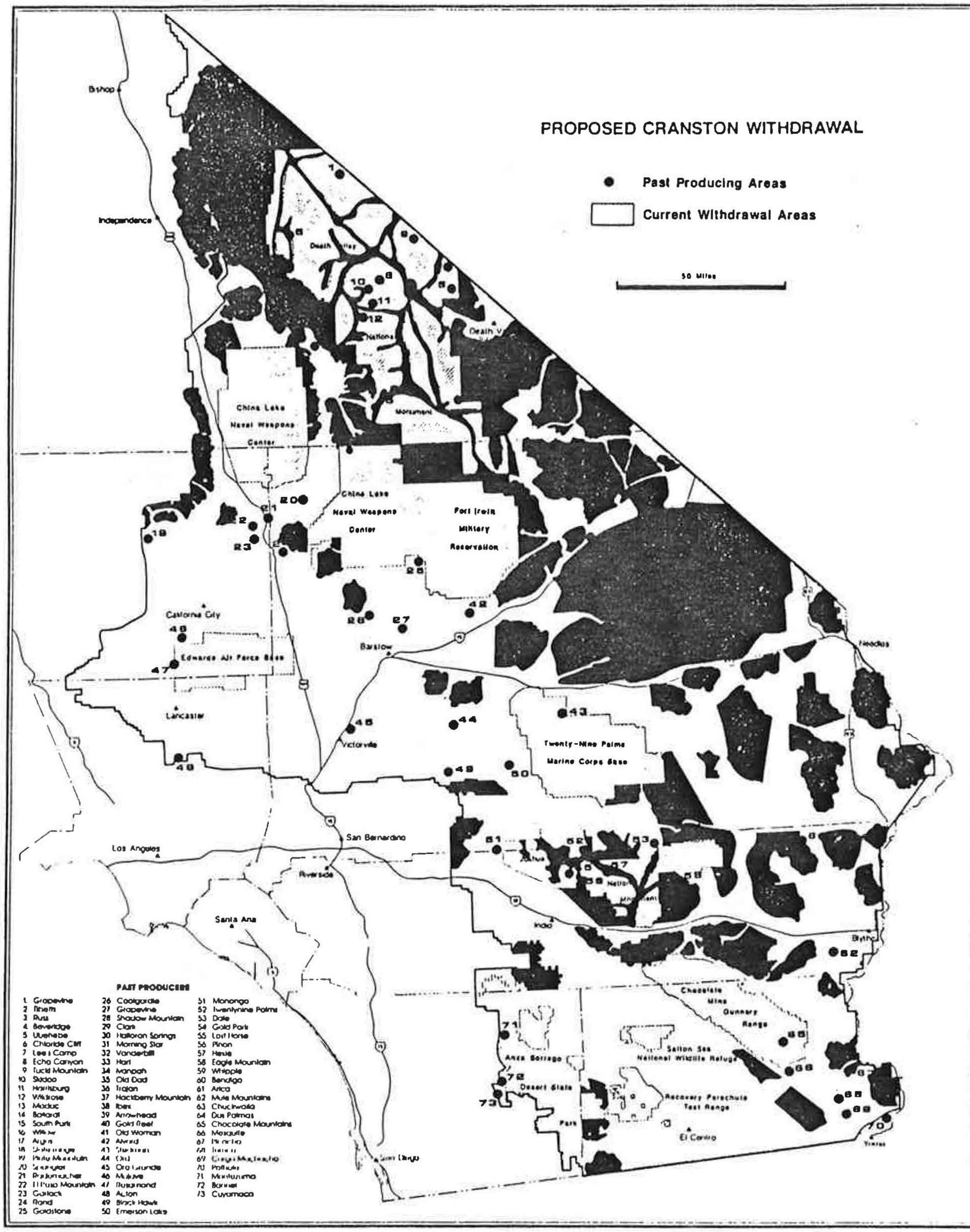
California, a rapidly growing and populous state has special land use problems. to better manage the available natural resources the California Desert Plan was established in 1980 and implemented by the Bureau of Land Management at a cost of S8 million. Certainly this first attempt at a full scale regional land management plan had problems and was unable to please everyone. But, the California Desert Conservation Act represented the first attempt to identify, inventory, and categorize resources, then determine their highest and best uses. Somewhere in the weighing of competing uses the BLM had to recognize that California had the 8th largest economy in the world in 1987, and it is projected to have the 6th largest world economy by 2010. Even more startling was the fact that southern California which contains the California Desert Conservation Area has the 10th largest economy in the world. The natural resources, particularly the industrial minerals needed to maintain a healthy and growing economy must be available for exploitation.

Unfortunately, many legislators believe that laws can be passed irregardless of the immutable laws of nature, like gravity or the laws of thermodynamics. Unsatisfied with the progress being made by the BLM these legislators and their supporters, have attempted to bypass any attempt at planning and resource inventory, by arbitrarily placing lands into the wilderness system. Part of their rational has been the need to conserve natural resources. A careful economic analysis of the practice of "banking" minerals for future generations was prepared by the International Institute for Economic Research in 1978. They had a fairly simple conclusion: "At any time during the twentieth century, enforced long-term conservation of mineral resources would have to be a poor economic decision for both the generation which made the decision and those which later used the resource" .

In times of rapidly changing technology we cannot accurately predict our future resource needs. It does seem probable that these needs may change in unexpected ways. It is likely that superconductors and ceramics will pay an increasingly important role in an industrialized society. Therefore, even meticulously prepared mineral surveys oriented towards evaluating the mineral potential of an area may well overlook mineral resources critical to our Nation's future.

Finally, the role of the mineral industry in the CDCA should be recognized. The 1987 Annual Report for the California BLM notes that between 1985 and 1987 Mineral Leases and Permits provided S203 million in revenues will require only about $11 million in management expenditures. Few government activities have a nearly 20:1 return on investment. In fact, this is nearly three times the entire BLM Budget over the same period. Clearly, mining pays its way in California.

It would be unfortunate if poorly conceived and irresponsible land use legislation were passed without giving the California Desert Plan an opportunity to work. Resources like the Hunter Mt. wollastonite deposit would be lost and ultimately it would be an extremely costly mistake, for which the citizens of California would ultimately pay.



PROPOSED CRANSTON WITHDRAWAL
Past Producing Areas
Current Withdrawal Areas
50 Miles
Bishop
Independence
Death Valley
China Lake Naval Weapons Center
Monument
Fort Irwin Military Reservation
California City
Edwards Air Force Base
Barstow
Lancaster
Victorville
Twenty-Nine Palms Marine Corps Base
Needles
San Bernardino
Los Angeles
Riverside
Santa Ana
Indio
Blythe
Chocolate Mtns Gunnery Range
Salton Sea National Wildlife Refuge
Anza Borrego Desert State Park
Recovery Parachute Test Range
El Centro
San Diego
PAST PRODUCERS
1 Grapevine
2 Ibex
3 Russ
4 Beveridge
5 Ubehebe
6 Chloride Cliff
7 Lee's Camp
8 Echo Canyon
9 Lucid Mountain
10 Skidoo
11 Harrisburg
12 Wildrose
13 Modoc
14 Ballarat
15 South Park
22 El Paso Mountain
23 Garlock
24 Rand
25 Goldstone
26 Coolgardie
27 Grapevine
28 Shadow Mountain
29 Clark
30 Halloran Springs
31 Morning Star
32 Vanderbilt
33 Hart
34 Ivanpah
35 Old Dad
36 Trojan
37 Hackberry Mountain
38 Ibex
39 Arrowhead
40 Gold Reef
41 Old Woman
45 Oro Grande
46 Mojave
47 Rosamond
48 Acton
49 Black Hawk
50 Emerson Lake
51 Morongo
52 Twentynine Palms
53 Dale
54 Gold Park
55 Lost Horse
56 Pinon
57 Hexie
58 Eagle Mountain
59 Whipple
60 Bendigo
61 Arica
62 Mule Mountains
63 Chuckwalla
64 Dos Palmas
65 Chocolate Mountains
66 Mesquite
70 Potholes
71 Montezuma
72 Banner
73 Cuyamaca

CONCLUSIONS

The West End Wollastonite Deposit at Hunter Mountain is the largest known deposit of high purity wollastonite remaining open to mineral entry in the western United States. The deposit is capable of supplying the rapidly growing markets for fillers in the western United States and Asia.

There is an opportunity for a wollastonite producer in the western United States. Currently, both wollastonite producers are located in New York State in the northeastern part of the United States. A producer in California is well located to supply customers in the west and could supply customers in the Pacific Basin and Europe.

Inclusion of this mineral resource into Death Valley National Monument is inappropriate. It will deprive Inyo County of needed jobs and an industrial tax base. Furthermore, designating land withdrawals by legislative fiat, without an assessment of resource potential is irresponsible. No nation, no matter how rich in natural resources, can long afford to waste its resource base.

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COMMERCIAL USES OF SEARLES LAKE CHEMICALS

by
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Paper Presented at Joint Conference Bureau of Land Management/South Coast Geological Society
March 1, 1989 - Irvine, California

INTRODUCTION

Thank you for this opportunity to tell you about Kerr-McGee's unique and economically important mining operations in Searles Valley. While Kerr-McGee has mining interests in many other minerals, many of which might be present in the California desert, I will confine my comments today to just Searles Lake. When I finish, you should have a good understanding of the importance of Searles Lake to the economy of California and to the life style we all enjoy in the United States.

UNIQUENESS OF DEPOSIT

The Searles Lake resource is unique because several unusual climatic and geologic occurrences had to come together to collect the suite of minerals found in our lake.

There had to be a river that drained into a large, enclosed basin that seldom overflowed into other basins or the ocean.

This basin had to be large enough and its air dry enough to evaporate the river to dryness for most of the time the river flowed into the basin.

The water in this river had to come from 3 sources; rain water containing ocean salts, ground water containing salts dissolved from young granitic rocks and sedimentary rocks, and water of volcanic origins. And these had to be in the right proportions to create the mineral suites found in the several salt beds.

All this had to occur within the last 300,000 years to keep the mineral beds from being buried too deeply, since this would compact them so much that they would lose their porosity and ability to transmit brine.

And finally, during recent times up through today the river had to be reduced in size so that it no longer flowed into the basin. This would allow the surface to dry completely and concentrate the minerals in salt beds. Both a dry surface and concentrated salt beds are necessary for economic mining.

MINERALS IN SEARLES LAKE

The mineral resources in Searles Lake are immense. There are about 4 billion tons of soluble minerals in just the top 4 salt beds. These have a market value at today's prices of over $200 billion. And there are deeper mineral beds that might have economic potential in the future when the resources in the upper beds become depleted.

At the rate the resources in the upper 4 beds are being depleted, Searles Lake could be mined for several more centuries. It has already been mined for about 3/4 of a century.

Searles Lake is the second largest sodium borate deposit in the United States. The largest deposit is also in the California desert. Worldwide there is only one other significant sodium borate deposit, and it is in Turkey, a politically unstable region. Mining is the only way to produce commercially important sodium borates.

Searles Lake is also the second largest natural soda ash deposit in the United States and probably in the world. The only alternative to mining natural soda ash is to make synthetic soda ash using the energy intensive, environmentally unsound Solvay Process.

The other primary minerals in Searles Lake are potash, sodium sulfate, and sodium chloride. While Searles Lake reserves of these minerals are large, there are other sources for these minerals that could be developed to supply the same markets. These, however, would be at higher cost to consumers and possibly at higher cost to our country because many of these alternate sources are foreign. Alternate sources might also have higher environmental impact than production in Searles Valley.

Searles Lake also contains large tonnages of many minor constituents that only lack appropriate technology for recovery. When improved technology makes recovery possible, Searles Lake could be the source of such other important chemicals as iodine, bromine, lithium, and tungsten.

USES OF PRODUCTS

The products from Searles Lake meet a wide variety of our Society's needs for raw materials. I will describe some of these Products during the rest of my talk.

BORAX AND RELATED PRODUCTS

Boron is used in many products; giving them properties that can be achieved no other way. It is the key constituent in making temperature resistant glass used in cooking ware, vacuum bottle liners, laboratory ware, and automotive headlights. Textile grade fiberglass would be impossible without boron. Textile grade fiberglass has consumer uses as diverse as tire cord, draperies, reinforced tape, and fishing rods, and industrial uses as diverse as reinforced pipe, filters in pollution control equipment, and reinforced safety equipment.

All of us appreciate the hard, dense, glass-like finish on our home appliances. It makes cleaning so easy. This finish is porcelain frit and you guessed it, boron is an important part of frit. Boron is also important in glazing ceramics such as dinner ware.

Insulation, used to keep our homes warm in winter and cool in summer, is made possible by boron. Boron keeps cellulose insulation safe by making it fire resistant. Boron also makes it Possible to spin the fine strands needed for fiberglass insulation.

A little known use of boron is control of setting time of gypsum wallboard that lines the walls of most of our homes.

Bright metal plating is another area where boron is important. It is the buffer that keeps the plating baths under control without affecting the products. Buffering is also the property of boron sought when it is added as a water softener in soaps and detergents and used in leather tanning.

Elemental boron fibers represent another growing use. These fibers give very high strength with little weight when used to reinforce recreational things as fishing poles and golf club shafts and exotic items such as rocket motors and structural components of high performance aircraft.

Boron also has selective biological properties. At low levels, it is an essential trace nutrient for our farm lands, and farmers are increasingly using boron supplements to maintain soil fertility. At high levels, boron in the form of boric acid is an effective, environmentally safe insecticide. In fact, some powder formulas used to control cockroaches are almost pure boric acid. Of course, boric acid has been used medicinally as a mild antiseptic for many years. And a growing biological use of boron is in wood treating. Here it is an environmentally safe alternative to using very hazardous chromated copper arsenate.

SODA ASH AND RELATED PRODUCTS

Glass manufacture is the largest consumer of soda ash, and container glass is the largest segment. Glass containers are used to hold food and beverage products without adding taste, hold medicines without contamination, hold chemicals without corrosion which could cause leaking, hold toiletries and cosmetics, and make fish bowls.

A second glass market is flat glass. This glass is used to make products such as automotive safety glass, windows and glass doors for buildings, display cases, and mirrors.

Another glass market is fiberglass insulation needed for energy conservation. This insulation allows us to burn less fuel, reducing both oil imports and reducing the CO2 emissions.

The function of soda ash in glass is to lower the melting temperature (again saving fuel) and increase fluidity enough to allow glass to be molded, cast or spun into desired shapes.

Another major market for soda ash is detergents. In this market it is used as both a direct additive to laundry, dishwashing, and industrial detergents, and to make other sodium based chemicals used in detergents. When added directly, soda ash is a softening agent that reduces soap scum. It also helps dissolve some types of oil and grease. Sodium based chemicals made from soda ash and included in detergents are sodium silicates and sodium phosphates. These soften the water and boost detergent activity.

Sing e soda ash is the lowest cost alkali, this leads to other major uses. One is acid neutralization, an important part of oil refining, chrome chemicals manufacture. and aluminum production. paper and cardboard production also rely on low cost alkali to break down the raw wood used to make paper.

Soda ash is used to make most of the other sodium based chemicals we use. Just a few of these are: sodium silicates used to make catalysts for petroleum refining and silica gel for absorbing moisture; sodium phosphates used in water treating and paint removal, and making paper, leather and oil drilling mud; sodium chromates used in corrosion control, as pigments in paints and inks, and in tanning leather; and sodium thiosulfate used to develop film. There are many other secondary sodium chemicals derived from soda ash.

Soda ash and its related chemicals are also finding use in pollution control. It is a low cost absorber to remove acid gases from industrial age power plant stacks. Soda ash is used to neutralize acid wastes, making them harmless. And soda ash can clean water by precipitating contaminants for settling.

And finally, soda ash and lower grades of sodium bicarbonate are used to increase the amount of crude oil that can be recovered from existing wells. This reduces the need to drill new oil wells.

POTASH AND RELATED PRODUCTS

The high productivity of America's farms is due in large part to the use of fertilizers to replace the soil nutrients removed by growing plants. This means we can feed our people while also preserving more land in its natural state for recreation and as Parks.

The three main fertilizers needed are nitrogen, Phosphate and potash. Searles Lake is the only commercial potash deposit in California, and is presently supplying nearly all potash used in the state.

The most common and lowest cost potash product is potassium chloride, also known as muriate of potash. Its principal use is for fertilizer for both the agricultural and consumer markets. It is also used in oil drilling mud and to make caustic potash and chlorine.

The other common potash product is potassium sulfate. Because its cost is higher, use of potassium sulfate in fertilizers is limited to those crops that are intolerant of chloride. These include nut crops, stone and citrus fruits, and tobacco. It is also preferred for the home fertilizer consumer who fertilizes many Plants with the same product. potassium sulfate is also used in making wallboard.

SODIUM SULFATE

Sodium sulfate has two major uses, paper and cardboard manufacture and powdered detergents, and several minor uses including glass manufacture. in paper and card board manufacture it supplies both the alkali and sulfur needed to break down wood to release the fibers. In detergents it is used as a builder to carry the detergents chemicals in the blend. In glass it is used to clarify the glass by removing bubbles.

SALT

Salt, or sodium chloride as it is known by chemists, was the first chemical produce, and sold as civilization developed. At one time it was even used as a type of money. In fact, it is the origin of the word salary.

Salt is the most widely distributed saline chemical in the world. Because it is easily recovered, it is also the lowest cost chemical. More salt is consumed annually than any other inorganic chemical.

Common home uses of salt include water softening, ice cream making, ice melting, food Preservation, and food seasoning.

Water softening is also a major industrial use of salt, where it is used to regenerate zeolite ion exchange beds. This affects such diverse enterprises as electric power generation, domestic water supplies, and secondary oil recovery.

The largest industrial use of salt is to make caustic soda and chlorine, both key industrial chemicals in our society. In many uses, caustic soda is interchangeable with soda ash, although it is usually more expensive. Unique uses for caustic soda include making Rayon fabrics, and specialty organic chemicals such as soaps and detergents, pharmaceuticals, dyes, flavors, and vitamins. It is the active ingredient in powdered drain openers (Drano). It is used to recover many of the specialty metals we need. And it is used to stabilize liquid bleaches. The largest uses for chlorine are: making plastics and solvents; as a disinfectant or bleach; to make specialty metals and pigments; and to make fire retardants.

Salt is the feed material for making elemental sodium. This is used to make specialty metals like titanium, zirconium and tantalum which are very corrosion resistant. Titanium is also used in high performance aircraft. Elemental sodium is also used as a catalyst, used to make dyes, pharmaceuticals and perfumes, and in sodium vapor lamps.

Salt is the principal raw material used to make sodium chlorate. This chemical, which is a Powerful bleach, is used to whiten paper. It is also used as a defoliant on cotton, which is important to mechanical harvesting. And sodium chlorate is one of the raw materials used to make the oxidizer for the fuel that propels the space shuttle into orbit.

SUMMARY

As you have seen, the chemicals from Searles Valley are the raw material for many other industries, from food production and pharmaceuticals, to rocket fuel, fire retardants and glass. And these are just a few of the uses for our products. Without these chemicals, our standard of living would be considerably lower than what we now enjoy.

BORAX, AN IMPORTANT INDUSTRIAL MINERAL

Presentation on Borax and its Uses

by

Mr. Eugene D. Smith, V.P. Gov't and Public Affairs

U.S. Borax and Chemical Corporation

I WAS ASKED TO TALK ABOUT THE IMPORTANCE OF U.S. BORAX'S BORAX OPERATIONS.

OUR FILM "BORON - LIGHT HEAVYWEIGHT" WHICH IS BEING SHOWN AT OUR EXHIBIT EXPLAINS OUR OPERATIONS AND EMPHASIZES THE IMPORTANCE OF BORAX AS AN INDUSTRIAL MINERAL MUCH BETTER THAN I CAN - AND - SO - I URGE ALL OF YOU TO STOP AT OUR EXHIBIT AND VIEW IT.

I WILL, AS OUR FILM DOES, EMPHASIZE THE IMPORTANCE OF OUR ORE DEPOSIT OF BORON, CALIFORNIA AND THE BORATE PRODUCTS WE PRODUCE. AND, I WILL, STRESS THE IMPORTANCE OF MINERALS, LIKE BORAX, TO SOCIETY.

THE IMPORTANCE OF MINERALS SHOULDN'T HAVE TO BE EMPHASIZED, BUT THERE ARE TOO MANY PEOPLE WHO PLACE MINERALS LOW ON THEIR PRIORITY OF ESSENTIAL ELEMENTS AND HOLD WILDERNESS TO BE A NATIONAL OBLIGATION.

THINK ABOUT THAT, MINERALS ARE OF MINOR IMPORTANCE TO SOCIETY AND WILDERNESS IS A NATIONAL OBLIGATION.

U.S. BORAX HAS HAD DIFFICULTY IN MAKING THE PUBLIC AWARE OF THE IMPORTANCE OF BORATES, FOR EXAMPLE,

DESPITE THE FACT THAT BORAX IS A VERY IMPORTANT INDUSTRIAL MINERAL, AND DESPITE THE FACT THAT OVER 100,000 PEOPLE PER YEAR VIEW THE BUREAU OF MINES VERSION OF BORON-LIGHT HEAVYWEIGHT, MOST PEOPLE THINK BORAX IS SOME KIND OF SOAP OR DETERGENT.

OUR HOUSEHOLD PRODUCTS AS ADVERTISED FOR MANY YEARS ON THE DEATH VALLEY DAYS RADIO AND TELEVISION PROGRAMS MADE THE 20 MULE TEAM TRADEMARK A HOUSEHOLD WORD - AND GAVE US THE IMAGE OF WESTERN PIONEERS WITH TRUE GRIT AND INTEGRITY.

BUT FEW PEOPLE KNOW THE IMPORTANCE OF OUR BORATE PRODUCTS TO INDUSTRY AND TO THE ECONOMIC WELL BEING OF CALIFORNIA AND THE NATION.

BORATES ARE WIDELY USED IN INDUSTRIAL INDUSTRY. THEIR PRIMARY USE IS IN THE MANUFACTURE OF INSULATION AND TEXTILE FIBERGLASS AND GLASS. INSULATION FIBERGLASS IS IMPORTANT TO THE REDUCTION OF THIS COUNTRY'S ENERGY CONSUMPTION.

ANOTHER FORM OF FIBERGLASS IS USED IN RE-ENFORCED PLASTICS TO REDUCE THE WEIGHT AND FUEL CONSUMPTION OF AUTOS AND TRUCKS.

BORATES ARE USED TO MAKE PYREX GLASS AND PORCELAIN ENAMELS.
BORON FIBERS ARE EMPLOYED IN THE PRODUCTION OF ADVANCED HIGH STRENGTH LIGHT-WEIGHT MATERIALS USED IN AEROSPACE VEHICLES.

THE ELEMENT BORON IS ALSO AN ESSENTIAL PLANT FOOD AND IMPORTANT TO AGRICULTURE IN THE BORON DEFICIENT AREAS OF OUR COUNTRY.

A SOMEWHAT NEW AND INTERESTING APPLICATION OF BORATES IS OUR PRODUCT TIM-BOR(R). THIS PRODUCT PROTECTS WOOD FROM FUNGAL DECAY AND ATTACK BY TERMITES AND OTHER WOOD BORING INSECTS.

U.S. BORAX HAS DONATED THIS PRODUCT TO THE NATIONAL PARK SERVICE FOR THE PRESERVATION OF THE SHIP WAPAMA AND THIS PRODUCT IS ALSO TO BE USED TO PRESERVE THE HISTORIC SHIP THE USS CONSTITUTION.

WHEN YOU VIEW OUR FILM YOU WILL BE SURPRISED BY THE MANY AND DIVERSE USES OF BORAX.

WHERE DOES THIS IMPORTANT MINERAL COME FROM? ABOUT 50% OF THE WORLD'S ANNUAL SUPPLY, (VALUED AT OVER $400 MILLION) IS PRODUCED IN CALIFORNIA, MORE PARTICULARLY IN THE CALIFORNIA DESERT CONSERVATION AREA. WE, U.S. BORAX, PRODUCE OVER 50% OF THE WORLD'S SUPPLY. ABOUT 50% OF THIS OUTPUT IS USED DOMESTICALLY AND THE REMAINING 50% IS EXPORTED TO IMPROVE THE NATION'S TRADE BALANCE.
ACCORDING TO THE 1988 BUREAU OF MINES REPORT, OTHER THAN CEMENT AND SAND AND GRAVEL, BORATES WERE THE MOST SIGNIFICANT NONFUEL MINERAL PRODUCED IN CALIFORNIA.

BORON IS A COMMON ELEMENT FOUND IN TRACE TO SMALL AMOUNTS THROUGHOUT THE ENVIRONMENT. HOWEVER, BORATE DEPOSITS OF CONCENTRATIONS THAT MAKE THEM ECONOMIC OREBODIES ARE VERY UNIQUE.

THE OUTSTANDING DEPOSITS ARE THE SODIUM BORATE DEPOSIT AT BORON, CALIFORNIA AND A COMPARABLE DEPOSIT IN TURKEY.

KERR-McGEE CORPORATION PRODUCES BORAX AS A BY-PRODUCT OF ITS BRINES OPERATIONS AT SEARLES LAKE, TRONA, CALIFORNIA.

THERE ARE A NUMBER OF SMALL COLMANITE AND ULEXITE DEPOSITS IN THE DEATH VALLEY AREA, THESE ARE CALCIUM AND SODIUM-CALCIUM BORATES. TWO OF THESE, THE BORAXO PIT AND THE BILLIE DEPOSIT, WERE OPERATED BY THE AMERICAN BORATE COMPANY.

THERE ARE SMALL OPERATIONS IN ARGENTINA, CHILE, CHINA AND THE SOVIET UNION.

THE AREA OF BEST POTENTIAL IN THE U.S. FOR BORATE DEPOSITS IS THE CALIFORNIA, NEVADA AND ARIZONA DESERTS, PARTICULARLY THE CALIFORNIA DESERT CONSERVATION AREA.
AS YOU ALL KNOW, SENATOR CRANSTON AND OTHERS PROPOSE TO DESIGNATE MUCH OF THE CALIFORNIA DESERT CONSERVATION AREA AS NATIONAL PARKS AND/OR WILDERNESS AND THEREBY CLOSE IT TO MINERAL ENTRY. THIS IS PROPOSED IN THE INTERESTS OF THE GENERAL PUBLIC AND FUTURE GENERATIONS. THE PROPOSAL IS BASED ON THE CONTENTION THAT ALL OF THIS AREA HAS BEEN EXPLORED AND HAS LITTLE, OR NO, MINERAL VALUE.

AS SOME OF YOU KNOW, THE BORAX DEPOSITS AT BORON WERE FOUND BY ACCIDENT, THE DISCOVERER, A DR. SUCKOW, WAS DRILLING FOR WATER AND NOT MINERALS. THE DRILLER SHOULD HAVE STOPPED WHEN HE DRILLED THROUGH THE ALLUVIUM AND INTO THE NON WATER BEARING GREEN SHALES THAT OVERLY THE BORATES. HE DIDN'T STOP

AND THE DRILL BROUGHT UP CUTTINGS OF COLEMANITE, A CALCIUM BORATE. EVEN THEN DR. SUCKOW WAS UNAWARE OF HIS DISCOVERY UNTIL HE HAD THE CUTTINGS ANALYZED.

THERE IS NO SURFACE INDICATION OF THE BORATE DEPOSITS AT BORON AND, AT THE TIME OF THE DISCOVERY, IT IS MORE THAN 50 MILES FROM ANY KNOWN BORATE OCCURRENCE. IT IS POSSIBLE THAT THIS DEPOSIT COULD HAVE REMAINED UNDISCOVERED TO THIS DAY. AND, IF WITHIN ONE OF THE AREAS TO BE WITHDRAWN UNDER S.7, NOW S.11, DESTINED TO BE FOREVER UNDISCOVERED.

DESPITE THE INITIAL DISCOVERY OF COLEMANITE AT BORON IN 1913, IT TOOK ANOTHER 13 YEARS TO FIND THE HIGHGRADE BORAX AND KERNITE DEPOSITS - THE SODIUM BORATES WE ARE MINING TODAY.

IN THE BEGINNING BORON WAS A RELATIVELY SMALL UNDERGROUND MINE WITH MILLING FACILITIES. MY FATHER WENT TO WORK AT BORON IN 1933 AND IN THOSE DAYS THERE WASN'T A BORON OR TOWN. THERE WAS A SANTA FE RAILROAD SIDING CALLED AMARGO WHICH WAS RENAMED TO BORON ABOUT 1941.

THERE WAS A DIRT ROAD FROM MOJAVE TO BARSTOW AND FEW PEOPLE BRAVED THAT DRIVE.

IN ADDITION TO THE COMPANY'S EMPLOYEES WHO BOARDED AT THE MINE, THERE WERE A FEW FAMILIES, SOME CATTLE, A FEW REAL-LIFE COWBOYS, SOME BOOTLEGGERS, A FEW PROSPECTORS, AND SOME GAMBLING JOINTS AND SPORTING GIRLS.

TODAY, AT BORON, WE MINE BY OPEN PIT WITH HIGHLY MECHANIZED EQUIPMENT. THE PROCESSING FACILITIES ARE ALSO MODERN AND INCORPORATE THE AUTOMATION AND CONTROL FUNCTIONS NECESSARY TO BE A LOW COST PRODUCER OF BORATE PRODUCTS AND TO OPERATE IN AN ENVIRONMENTALLY SAFE MANNER.

SINCE REGULAR OPERATIONS BEGAN IN 1927, WE HAVE PRODUCED OVER 75 MILLION TONS OF BORATES. TODAY THE PRODUCTION RATE IS ABOUT 3 MILLION TONS OF ORE PER YEAR.

THIS REQUIRES AN ANNUAL PAYROLL AT BORON IN EXCESS OF $23 MILLION AND THE PAYMENT OF KERN COUNTY PROPERTY TAXES OF OVER $4 MILLION.
IT REQUIRES 800 EMPLOYEES AT BORON AND 600 MORE IN OUR RELATED FACILITIES AT WILMINGTON, ANAHEIM, LOS ANGELES AND OUR SALES OFFICES.

IT REQUIRES AN OPEN PIT MINE, THE PRESENT AREA OF WHICH IS ABOUT 550 ACRES, LESS THAN ONE SQUARE MILE. THE MINE, OVERBURDEN PILES, AND PROCESS FACILITIES OCCUPY ABOUT 5,000 ACRES.

THE IMPORTANCE OF U.S. BORAX BORON OPERATIONS TO KERN COUNTY, THE STATE OF CALIFORNIA AND THE NATION THROUGH THE PRODUCTS IT SUPPLIES AND THE REVENUES IT GENERATES IS EVIDENT.

WHEN YOU CONSIDER THE VALUE OF THE TO 75 MILLION TONS OF BORATES PRODUCED (THATS PRODUCT) AND THE SMALL LAND AREA IMPACTED,5,000 ACRES - IT IS ALSO CLEARLY EVIDENT THAT OUR BORON OPERATION IS THE HIGHEST AND BEST USE - THE HIGHEST AND BEST USE OF THIS LAND.

I HAVE TO ASK THE ENVIRONMENTALISTS, ARE OPERATIONS LIKE BORON LESS IMPORTANT THAN WILDERNESS? DON'T THE BENEFITS OF THE MINERALS PRODUCED MORE THAN JUSTIFY THE L#NDS DISTURBED? <u>PARTICULARLY WHEN MATERIALS ARE ESSENTIAL TO PRESENT AND FUTURE GENERATIONS. ALSO, DOESN'T THE FACT THAT PRESENTLY KNOWN BORAX RESERVES HAVE A FINITE LIFE, DOESN'T THAT DICTATE THAT THE SEARCH FOR</u>

NEW RESERVES IS IN THE NATIONAL INTEREST?

I DON'T KNOW HOW MANY OF YOU HAVE READ "BLUEPRINT FOR THE ENVIRONMENT", THE ENVIRONMENTALISTS' RECOMMENDATIONS TO THE NEW PRESIDENT. I AM SURE THAT THOSE OF YOU WHO HAVE READ IT WERE AS SURPRISED AS I WAS AT HOW OPENLY THE ENVIRONMENTALISTS ADVOCATE BIRTH CONTROL TO PROTECT THE ENVIRONMENT.

I DON'T WANT TO TAKE A POSITION ON BIRTH CONTROL BUT I DO OBJECT TO THE ENVIRONMENTALISTS PLACING THEIR ENVIRONMENTAL GOALS AHEAD OF CHILDREN.

I FIND IT DIFFICULT TO UNDERSTAND HOW ENVIRONMENTALISTS CAN PROPOSE THE PROTECTION OF SO MUCH WILDERNESS WHEN THEY KNOW THAT SUCH WILDERNESS LOCKS UP THE RESOURCES SO NECESSARY TO THE NEEDS OF FUTURE GENERATIONS.

I BELIEVE WE MUST USE ALL OUR RESOURCES IN ORDER TO MEET ALL THE NEEDS OF FUTURE GENERATIONS. WE CAN NOT TAKE THE POSITION, AS THE WILDERNESS SOCIETY HAS - THAT 42 YEARS OF BORATE RESERVES, 140 YEARS OF RARE EARTH RESERVES, AND 770 YEARS OF SODIUM CARBONATE RESERVES - ARE ADEQUATE FOR FUTURE GENERATIONS.

HOW CAN THESE PEOPLE PLACE SO LITTLE VALUE ON THE IMPORTANCE OF THE MINERAL RESOURCES THAT ARE ESSENTIAL TO FUTURE SOCIETY. . . .

PERSONALLY, I PREFER KIDS. I LIKE KIDS AND I AM PROUD OF THE YOUNG MEN AND WOMEN OF OUR COUNTRY. I FIND MOST OF THEM TO BE INTELLIGENT, RESPONSIBLE, MATURE, AND EAGER TO MAKE THEIR PLACE IN SOCIETY. I THINK WE SHOULD STRIVE TO MAKE ROOM FOR THEM IN OUR SOCIETY.

WE AT U.S. BORAX ARE PROUD OF WHAT WE DO AND WHAT WE DO FOR SOCIETY. WE KNOW HOW IMPORTANT FOOD, CLOTHING AND SHELTER ARE TO THE HUMAN RACE AND HOW IMPORTANT MINERAL RESOURCES WILL BE TO FUTURE SOCIETIES.

TO QUOTE THEODORE ROOSEVELT FROM HIS DECEMBER 3, 1907 MESSAGE TO CONGRESS,

> "TO WASTE, TO DESTROY, OUR NATURAL RESOURCES, TO SKIN AND EXHAUST THE LAND INSTEAD OF USING IT SO AS TO INCREASE ITS USEFULNESS, WILL RESULT IN UNDERMINING IN THE DAYS OF OUR CHILDREN THE VERY PROSPERITY WHICH WE OUGHT BY RIGHT TO HAND DOWN TO THEM AMPLIFIED AND DEVELOPED."

WE, THE MINING INDUSTRY, MUST CONVINCE THE PUBLIC TO SUPPORT WHAT WE DO RATHER THAN SUPPORT THOSE WHO WANT TO STOP THE WORLD.

INDUSTRIAL ROCK AND MINERAL RESOURCES OF ARIZONA WORKSHOP PROCEEDINGS

By E.W. TOOKER, Compiler-editor

Prepared in cooperation with the Arizona Geological Survey

Workshop considerations of current resource availability, resource problems, new search technology, information needs of users; and recommendations for improving research programs for the industrial rock and mineral resources

U.S. GEOLOGICAL SURVEY CIRCULAR 0000

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Chapter 6

ENERGY RESOURCES

OVERTHRUSTING MODELS FOR THE SOUTHERN SIERRA AND ADJACENT DESERT REGION: A KEY TO NEW ECONOMIC OPPORTUNITIES

by

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Geothermal Program Office
Naval Weapons Center, China Lake, CA

and

James L. Moore
Vice President, Exploration California Energy Company, Inc.

INTRODUCTION

The interpretation of the geology of the Western United States is in a great state of flux. This situation is leading to the demise of many cherished and long-held concepts and to the uncertainty and excitement of finding new interpretive treasures in what has been considered by many to be a totally explored and conceptually understood arena. This modern pulse of change was called out clearly in recent times by David R. Lageson of Montana State University in "Regional Tectonics of the Cordilleran Fold and Thrust Belt" (1982 AAPG Fall Education Conference), in which he stated:

> "A regional tectonic synthesis of the North American Cordillera is currently being pieced together through paleomagnetic and stratigraphic data coupled with new plate tectonic concepts and kinematic models. Text books are literally being rewritten on the tectonic geology of western North America based on the microplate or exotic terrane theory of continental accretion."

We believe that we too are contributing to the growing understanding of the geology of western North America, and to a rekindling of the need for people to look again at the data that pertain to the southern Sierra Nevada and vicinity. We urge that workers in the area emulate us by trying to discerne and examine the uninterpreted raw data, then to see how many new and different ways the data can actually be interpreted. New interpretations of the data are most apt to lead the explorationist to the hidden anomalies that we call mineral deposits.

Much of the information given in this paper was presented on 6 June 1987 in Los Angeles, Calif. as an invited paper at the Energy and Minerals Session of the 1987 National Meeting of the American Association of Petroleum Geologists the complete text of which appeared in NWC TP 6841. We hasten to state that we do not expect our interpretations to stand unchanged for all time. Rather we believe our interpretive model to be the best fit for the data in hand today.

Certainly this model will present a challenge to traditionalists and explorationists alike to examine every facet of the data once again to see if we have stumbled or if we have truly opened a new vista for all to exploit. In particular, we hope our interpretations, as expressed in this and other recent papers, excite people to reexamine the Sierra Nevada and the southwestern Basin and Range province, to seek new data, and as result to find new mineral and energy deposits.

We would remind our audience that our geologic model for the Coso region is based on fundamental concepts and data that are not novel to those who are students of the history of geology as a science, especially as this geology pertains to our specific geographic area of study. The debates of regional compression (folding and thrusting) in the Basin and Range versus regional extension (grabens and horsts) have been with us for many generations. We have simply taken the data package for the Coso geothermal area and surrounding region as we understand it today, and have made what we think is the most logical and best fitting model for ourselves and others to test.

In the 1870's proponents of the battle of tension versus compression for this region formed sides. Clarence King, writing initially in the "Atlantic Monthly" and the "Overland Monthly" in 1871 and then in "Mountaineering in the Sierra Nevada" (now available through the University of Nebraska Press), stated regarding the Sierra Nevada Region:

> "In the late Tertiary period a chapter of very remarkable events occurred. For a second time the evenly laid beds of the sea-bottom were crumpled by the shrinking earth . . ."

Within 3 years, this concept of compression during the late Tertiary in the general Sierran region was countered by Gilbert,s classic extensional model for the Basin and Range, published in 1874. Although Spur (1901) raised some doubts over Gilbert's concepts, Baker (1913) was the one who truly rekindled the thrusting model for the southwestern Basin and Range. As time progressed more and more investigations of the Basin and Range concerned the geometric improbability, if not outright impossibility, of mountain building through extension. Davis (1925) raised the very same questions the Consortium for Continental Reflection Profiling (COCORP) study (1987) by Allmendinger attempted to address. Davis was followed by Willis (1934) and Lawson (1936), both of whom described the east front of the Sierra as a thrust fault. Mayo (1941), in his mapping of the faults of the Sierra Nevada front, addressed the complex nature of the eastern front of the Sierra and noted once again that most of the faults he observed were reverse faults. Nolan (1943) raised virtually the same issues of fault geometry.

In 1979, the United States Navy, at the Naval Weapons Center (NWC), China Lake, Calif., undertook a new and unique project. This project was to contract for the exploration and development of a portion of the Coso geothermal system, with private industry using private-sector capital, i.e., no capital cost to the Navy. The California Energy Company as the Navy's contractor discovered a superb resource. Together we, California Energy, and the Geothermal Program Office of NWC have learned some startling and exciting geology along the way.

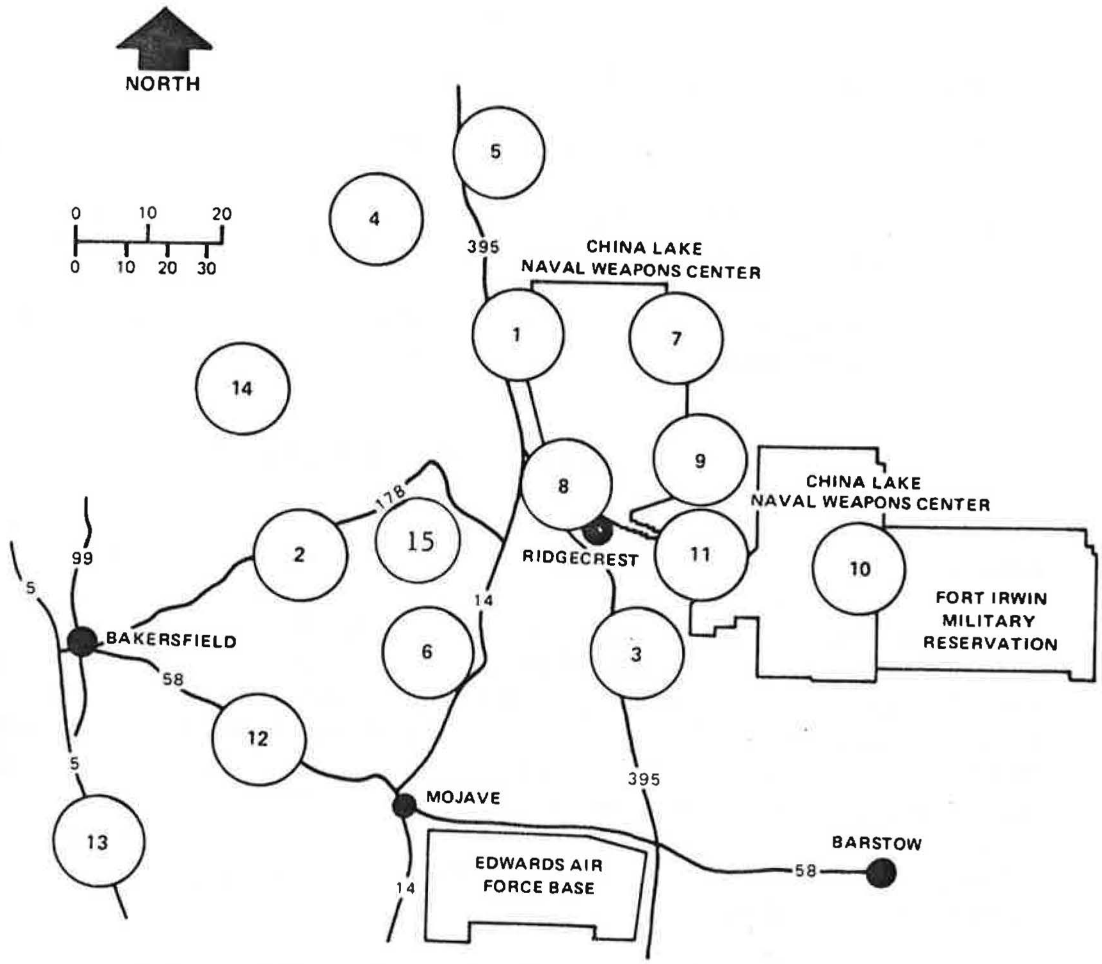

FIGURE 1. Areas of Geothermal Potential in the Vicinity of the Naval Weapons Center That Have Acted as Centers of Mineral Deposition.

Features of the Area

Satellite views of the Coso geothermal system reveal several prominent features. The following list of features must be accounted for, whatever the structural model chosen.

1. Major northwest fracture zones, offsetting the Sierra front

2. A perlite dome field that is strung out in a north-south direction along the east side of a granitic ridge and that lies in what appears as a circular fracture system

3. An arcuate apparent inward-dipping fracture system that is about 20 miles in diameter

4. A series of scallop-shaped fractures of some sort, aligned along the eastern Sierra front

OBJECTIVES

The primary objectives of this paper are to present:

1. The results of exploration along the eastern edge of the southern Sierra Nevada.
2. Some interpretations of structures of the southern Sierra Nevada and adjacent Basin and Range that seem consistent with all of our geological findings.
3. Economic implications of the structural interpretations that have resulted from the successful exploration of the Coso geothermal system.

COSO GEOTHERMAL SYSTEM

Our general area of interest is the southeastern Sierra Nevada and the ranges immediately to the east. Over the past several decades, the Sierra has been referred to as the westernmost range of the Basin and Range both as to position and structure. However, with the burgeoning evidence for pervasive low-angle faulting throughout the Basin and Range, characterized by some as a region of asymmetric 1/2 grabens, plus the increasing recognition by active field workers of low-angle faulting within the Sierra itself and the resulting rather obvious conclusion of probable detachment of the Sierra Nevada, no longer can we arbitrarily draw a meaningful tectonic boundary at the eastern edge of the Sierra. Instead, we believe the whole region must now be considered as an integral part of the entire Basin and Range complex, which would then extend from at least the overthrust belts on the east to the western edge of the Sierra Nevada as it dips beneath the Great Valley which is itself a zone of extensive thrust faulting.

A fundamental question for serious study of the Coso geothermal system is whether Coso is an isolated phenomenon or simply a part of a series or swarm of similar features. The latter seems to be the case. We recognize what we think should be considered as at least 14 mineralizing centers or systems in the general vicinity of the Coso geothermal system (Figure 1) and are increasingly confident a 15th mineralizing center lies a short ways south and west of Walker's Pass. All of these potential prospects have surface expressions that include some of the following at each site:

1. High surface heat
2. Young volcanic rocks
3. Distinctive geochemistry or associated ore deposits
4. Arcuate fracturing

Several of these prospects have truly impressive overlying or adjacent hydrothermal alteration zones with associated epithermal precious metal prospects. Coso is not a single isolated phenomenon and a careful evaluation of the thrust fault and lystral fault complexes of the region should disclose zones of major mineral deposition, heretofore unrecognized.

In addition to the prominent perlite dome field, the Coso area has numerous small natural steam vents plus extensive steam venting from old exploration drill holes at several old mercury prospects and workings, Over 42 venting old steam wells and hot water pools may be found at the former main Coso Hot Springs Resort area (Figure 5), which is located on a fault at the eastern edge of the central granitic ridge.

STRUCTURAL SETTING: THE UPLIFT PROBLEM IS NOT NEW

NOTES FROM "STRUCTURAL GEOLOGY OF NORTH AMERICA" BY EARDLEY (1951) ON BASIN AND RANGE

- FROM NOLAN (1943) "TILTING, THE EFFECTS OF WHICH HAVE BEEN OBSERVED IN THE REGION, APPEARS IMPOSSIBLE OF ACCOMPLISHMENT UNLESS ACCOMPANIED BY EITHER PLASTIC FLOW OR WIDESPREAD SHEARING AT RELATIVELY SLIGHT DEPTHS"
- "SHORTENING OF THE CRUST MAY BE A RESULT OF NORMAL FAULTING IF THE RADIUS OF CURVATURE OF THE FAULT PLANE IS LESS THAN WIDTH OF THE TILTED FAULT BLOCK."
- FROM DAVIS (1925) "--- THAT THE FAULT PLANES ARE CURVED AND FLATTEN IN DEPTH, IF BORNE OUT BY FUTURE WORK, WOULD INDICATE THAT THE TILTING COULD HAVE BEEN CAUSED BY ROTATION OF THE BLOCKS ON SUCH CURVED PLANES; AND IT IS POSSIBLE THAT THE SHORTENING DUE TO TILTING MAY BE OF GREATER MAGNITUDE THAN THE EXTENSION RESULTING FROM NORMAL FAULTING."

FIGURE 2. Notes From Structural Geology of North America

Exploration and Development

California Energy Company has drilled a number of successful wells that range in depth from 1500 to 8000 feet and encounter a wide range of rocks and attendant alteration products. Wells in the field range up to well over one million pounds per hour (pph) mass flow in capacity and to over 700oF in temperature.

Following a drilling program from late 1981 to March 1986, a decision was made to construct the first power plant. This power plant is a dual-flash unit, designed and manufactured by Mitsubishi and erected by Guy F. Atkinson. This initial 25-megawatt plant officially went on line 15 July 1987 and has been followed by 4 more turbines, designed and manufactured by Fuji and installed by Mission Power Engineering, in production plus 4 additional units under various stages of construction or final planning and permitting.

With this background of successful exploration drilling and commercial development, let us study the issues of both regional structural geology and specific reservoir geology as we see them at Coso today. We recognize quite clearly that the mortality rate for exploration models is high, but the data we have in support of our model are, in our opinion, both extensive and significant.

Just as an ore deposit of metals is an anomaly in the broad structural fabric of a region, so is an active geothermal system an anomaly. We must understand the broad framework or structure that hosts this anomalous feature if we are to be anything more than amateur prospectors. In the case of the Basin and Range, the arguments over fundamental structure that are raging today are not new. Consider the words of Nolan (1943) or Davis (1925), as shown in Figure 2, both of whom clearly recognized even then the improbability of the classic graben and horst model that stemmed from Gilbert,s work in 1874.

Demise of a Classic Concept

Ponder the COCORP 40-degree North Transect by Allmendinger (1987) and note the increasing recognition of the demise of the classic graben and horst concepts of the past century as they founder on mass balance, the laws of physics, and the revelation of the third-dimensional data that have remained proprietary for decades but are now becoming available (Figure 3).

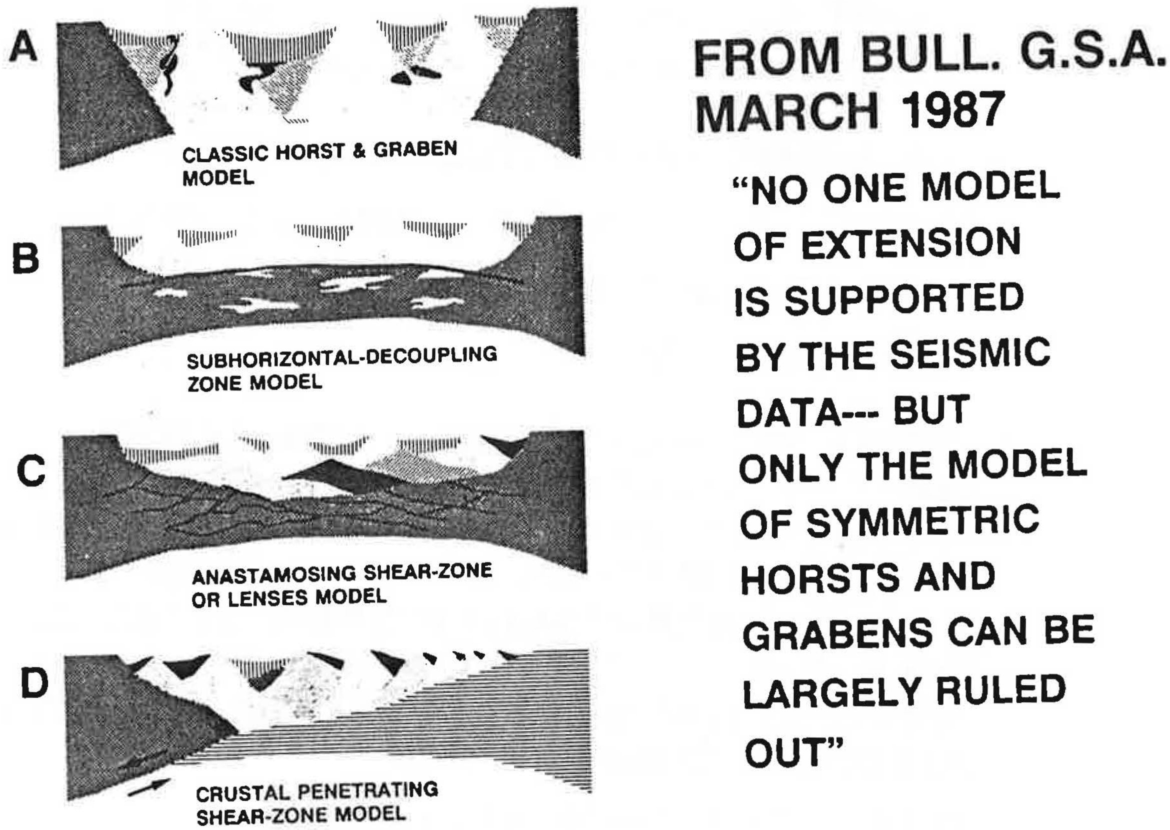

FIGURE 3. Models of Extension From the Bulletin of the Geological Society of America.

We who study Coso are not just plunged into the exciting new debates over the very character of the Basin and Range, but we are intimate participants in the fundamental plhilosophic debates of the very origin of intrusive systems. We subscribe to mid-crustal melting, granitization if you like, with some co-located basaltic leakage of a sub-crustal origin for the main localized heat source at Coso. However, we also recognize the far greater green schist metamorphic heat source of a regional eztent that seems to be below the shallower intrusive system. Figure 4, a quote from GSA memoir 28 illustrates the fundamental disputes involved.

THE ORIGIN OF THE GRANITIC MAGMA
AT COSO

MID-CRUSTAL GRANITIZATION
VS
DIFFERENTIATION OF UNDERLYING BASALT

FROM GSA MEMOIR 28, "ORIGIN OF GRANITE" (1947)

- "THIS QUESTION OF THE ORIGIN OF GRANITE IS PERHAPS THE MOST LIVELY OF GEOLOGIC TOPICS TODAY - BUT WE SHOULD REMEMBER THAT IT ALWAYS HAS BEEN"

- "BIGOTS, OR IF YOU LIKE, ENTHUSIASTS, ON BOTH SIDES DO A DEAL OF HARM, AND PONTIFFS, I SUGGEST TO PROFESSOR BOWAN, WHILE CAPABLE OF A GREATER NUMBER OF GOOD DEEDS, ARE ALSO CAPABLE OF A GREATER NUMBER OF BAD DEEDS THAN THE VILLAGE DRUNK. IF WE KEEP OUR TEMPERS, WHILST NOT PULLING OUR PUNCHES, WE SHALL RECEIVE GREAT PROFIT AND PLEASURE FROM THESE DEBATES."

THE FOLLOWERS OF BOWEN (1915) VERSUS THE FOLLOWERS OF READ (1943) AND BARTH (1948)

FIGURE 4. The Origin of the Granitic Magma a Continuing Debate

Thrusting, an Old But New-Found Concept

Our interpretation of the nature of the eastern margin of the Sierra Nevada is what many will consider a new concept. The classic view of the Sierra as a deep, some would say 85,000-foot deep, block of granitic rock bordered by an immense normal fault on its eastern margin founders on several problems. These problems include gravity, heat flow, geochemistry, isotope chemistry, and structure such as the anticlinal folding and faulting of adjacent valley-fill sediments with these anticlines and faults simply disappearing beneath the granitics. We believe that a Sierran model based on thrusting is an attractive interpretation that answers many questions and is consistent with all that we know today. Figure 5 shows three different views of the origin of the Sierra Nevada-Coso area.

THE NATURE OF THE SIERRA NEVADA - COSO AREA

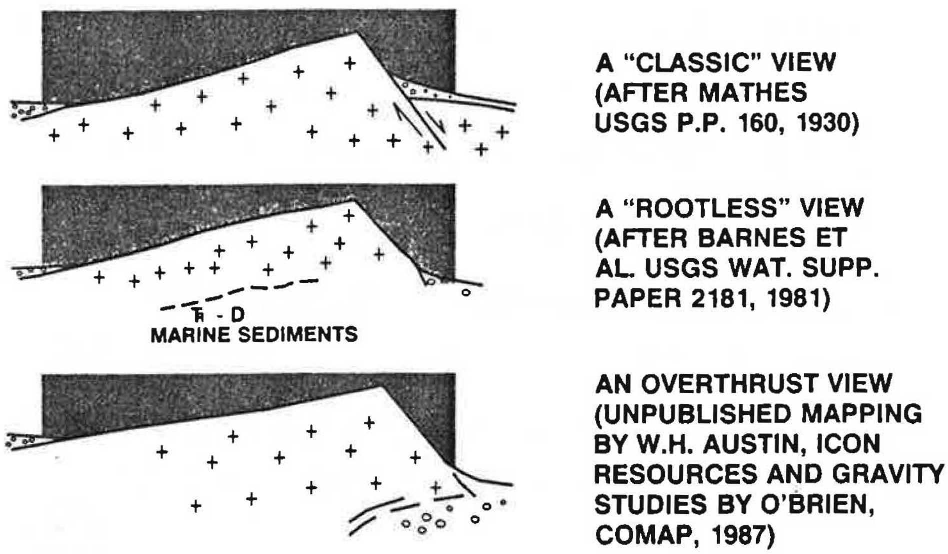

FIGURE 5. The Nature of the Sierra Nevada—Coso Area

The compressional history of the southern Sierra Nevada and the adjoining areas on both sides of the Sierra, as outlined in Figure 6, is clear cut. Let us briefly look at these features: an intense Pliocene compressional overprint, episodes of warping, and some newly recognized thrusting in the San Joaquin Valley on the west side of the Sierra Nevada.

Baker (1913) began the debate over thrusting in the Basin and Range, and scientists such as Peter Misch (1960) and Harry Wheeler continued the advocacy with overthrusting details. The theory of thrusting is increasingly with us today.

As an example of these growing interpretive forays, a typical proprietary study of a classical area within the Basin and Range dating from a few years ago shows thrusting, a major thrust ramp, and extension on the surface in the form of thin tectonic denudation slices.

Coso is clearly within the Laramide zone of activity, being located essentially where Eardley (1951) would grade the Central Rockies into the southern Arizona Rockies. We use Eardley's excellent text as a reference to show that our ideas are not so much new as a reemphasis of existing problems and concepts that need to be reexamined in the light of extensive industrial experience now becoming available to the geologic community at large.

COMPRESSION OF THE COSO AREA - WHEN?

- BASIN AND RANGE (SOUTHERN) THE RESULT OF COMPRESSION - BAKER, J. GEOL. 1913
- LARAMIDE OVERPRINT - EARDLEY 1951
- PLIOCENE OVERPRINT - EARDLEY, 1951
- REPEATED WARPING AND PROFOUND MID-PLIOCENE OROGENY - HEWETT, 1954
- THRUSTING IN SOUTHERN SAN JOAQUIN VALLEY - UNPUBLISHED, EUREKA RESOURCES*

*Unpublished document, Eureka Resources, El Cerrito, Calif.

FIGURE 6. Compression of the Coso Area

Of far greater local interest and certainly more timely in terms of new thrusting or rejuvenated motion on older thrusts, a zone of Pliocene thrusting is clearly demanded for the Coso area by Eardley (1951). We cannot help but note the obvious block Eardley showed on the south side of the Garlock Fault for which NASA scientists have recently described the rotational geometry. Coso is in that prominent zone of thrusting north of the Garlock Fault.

Hewett (1954), in his chart of deformational events in the region that includes Coso, notes warping from mid-Miocene to the beginning of late Pleistocene, with, in his words, profound orogeny and folds and thrusts. At the end of mid-Pliocene, with the thrusting from this orogeny very evident in the Panamint Mountains, motion would most likely occur on older thrusts within this area as well, such as the ex

Given the existence of a thrusting in the region of Coso, is the vulcanism at Coso reflective of an offset heat source that is lost to the west under the Sierra, or is the heat source still located below Coso: This question is vital in evaluating the size and location of all of the potentially mineralized zones that may be associated with the 15 centers defined in Figure 1.

A cross section, prepared by Fournier and Thompson (1980) showed both the recharge patterns for the Coso reservoir and the importance of the pervasive fracturing and breakup of the thin thrust sheet of Sierran granitics. This process of thrusting and breakup provides the massive permeability in the Sierran recharge zones as well as in the reservoir itself and is what enables the shallow portion (upper 2 miles) of the Coso geothermal reservoir to be so highly productive.

Fractures as Critical Elements

To compound our problem of structural interpretation, recent mapping in Coso shows a problem faced by anyone mapping or using maps: the question of which fractures to show and which to ignore. A person planning a commercial drilling campaign does not drill regional models, but drills actual fracture patterns, with the intent to be a sharpshooter as opposed to relying on a scatter-gun drilling effort, in the evaluation of the actual structure present at Coso, one cannot blandly ignore the fracture pattern so clearly suggested by linear arrays of perlite domes. These obvious fractures and their intersections are critical elements of the reservoir and critical drilling targets, whether covered by veneers of volcanic debris, and whether or not they fit some popular regional model of the geology. Indeed, the north south fractures at Coso appear to be the result of local folding rather than a fundamental structural framework.

In general terms the actual drilling targets being sought at Coso (which structures are probably the most potential hosts for ore zones at each of the mineralized centers in the region) are:

1. Vertical breccia pipes or zones, both volcanic and hydrothermal in origin (probably the most productive zones found to date)

2. Fracture intersection breccias

3. Linear breccia zones

4. Spreading fracture networks (the least productive geothermally to date but of great value as injection sites)

In particular, given stacked thrusting sheets, many of these features will occur between thrusts, being confined to a particular sheet owing to the physical properties of the particular sheets themselves. A superb example in this region would be the Defiance pipe (Pb and Ag ores) located wholly beneath the Davis thrust.

The model selected for the Coso geothermal field must account for the following features:

1. The 20-mile-diameter arcuate fracture pattern

2. The north-south fractures cresting the folded granitics of the central ridge

3. The prominent north-west fractures that offset the Sierran granitics

4. The radial fractures within the Coso geothermal field

5. The geochemistry of the steam wells and carbonate mounds of the area

6. The over-thrusting seen in adjacent valleys and ranges

An example of Item 6 is seen in mapping by Ward Austin (1987) of Icon Resources, Ltd., Lakewood, Colo. and detailed gravity interpretation by O'Brian of Comap Exploration Services, Inc., Lakewood, Colo., who showed the Indian Wells Valley south of Coso to be overthrust by at least 7 kilometers. In effect, 7 kilometers of granite have moved out over the valley fill. Not only has Silver (1986) of CalTech found, mapped, and published on the stacked low-angle faults in the Sierra just south of Indian Wells Valley, but the air-photo and gravity data are also powerfully supportive of thrusting along much if not all of the southern Sierra front, including the portion adjacent to Coso.

Modeling of the Coso Area

We are realists enough to recognize that our interpretations will excite controversy among traditionalists, and many more generations will be required to resolve the mechanics of Basin and Range Fault formation, not to mention the debates over the origins of granite.

Our exploration model for Coso shows the Sierra thrust eastward as an "exotic" terrain of a rootless nature, riding with and over marine sediments. The folded granitics of the central ridge which are to date the producing portion of Coso are the "rolled over" leading edge of a thrust sheet, and the active intrusive below is tucked into the underlying thrust ramp slightly to the west. Motion on the Coso system of thrusting apparently postdates one perlite dome, one we believe now to be a rootless dome dated at approximately one million years.

We propose that the marine sediments believed to underlie the Sierra are beneath Coso (and the Argus Range too) and that this marine sediment layer is the source of both the hydrocarbons in the steam at Coso and the increasing chloride at depth.

Economic Implications

The economic implications of our structural model for Coso and the southern Sierra Nevada and the adjacent Basin and Range are exciting. Obviously, we can neither prove nor disprove our model at this stage, but we would point out that neither popular dogma nor controversy has any probative value. Rather, the market place will be our real judge. If the model we show for the southern Sierra Nevada is believable to the exploration community, then a number of economic possibilities exist which warrant testing by industry and local municipalities.

The single most important result of a structural model based on compressional geology as the dominant element is that the geologic evaluations of the potential for major mineral resources in the desert and eastern Sierra must be totally redetermined. This means that such simple things as determining exploration strategies for individual mineral properties must be rethought, and that the broad regional evaluations of resource potential that have been done in particular for the support of various wilderness and park proposals have deeply underestimated the mineral worth of the desert. Let us consider some specific types of deposit potentials briefly:

1. Geothermal Deposits. Each of the 15 mineralization centers shown in Figure 1 has a geothermal potential. A number of these have geologic, geophysical and geochemical signatures that rival the Coso system currently under development. If even a small fraction of these can be placed in production, the national reliance on foreign oil can be reduced and the quality of the air in the South Coast region can be dramatically improved. If the Coso shallow reservoir (the top two miles, that is above the green schist region) meets its expected potential, Coso alone will offset burning 10,000,000 bbls of oil per year in the southcoast air basin. As environmental standards impact older fossil fuel plants in the Southern California region more stringently in the next few years, the need to explore for and develop geothermal resources will undergo a dramatic increase. The most optimistic public statements by the major public utility in the region is that new generating capacity is needed by 1996. Privately, utility officials and energy suppliers state there will be a major need by 1992. No matter who one chooses to listen to, this need will in turn drive exploration and development rapidly in the next decade. The geothermal worth of the desert region can also have a special impact on a unique problem regardless of power needs if such development is allowed to continue in the desert regions of the western United States. This problem is the worldwide accumulation of "greenhouse gasses". Science News on 24 December 1988 notes that a small electric utility, Applied Energy Services of Arlington, Virginia, is arranging to plant 50 million trees to offset

a new 180 megawatt coal fired power plant they are building. This offset will cost $2 million corporate dollars plus $10.7 million in taxpayer dollars, which works out to $2,300 per year per megawatt offset. Thus the present 240 megawatt development at Coso, which is non-CO_2 emitting, will apparently save the rate payers and taxpayers some $552,000 in annual CO_2 abatement costs when compared with an equivalent coal fired plant. One can reasonably assign a probable success rate for the 15 known or suspected geothermal deposits close to the Ridgecrest area: let us assume a 25% success rate; and a full power potential of 600 MW for each of these shallow reservoirs produced. Doing so we can thus conclude the presently known or suspected geothermal deposits in the local desert region, if allowed to be developed, will equal the planting of 625 million trees at a cost of approximately $158,750,000 per year. This of course raises a dramatic question, namely the worth of the desert as wilderness, as opposed to the worth of the desert as a source of power that does not contribute to what many see as a worsening "greenhouse" affect. Portents of change are clear cut in bills such as that recently introduced by Sen. Wirth of Colorado, whose bill would seek to reduce U.S. carbon dioxide emissions by 20% by the year 2000. The environmental advantages of producing geothermal deposits appears noteworthy.

2. Oil and Gas. It is in the area of oil and gas that an overthrust model for the region has its most dramatic potentials. As a microcosm of this, consider the major thrusts of the Ivanpah quadrangle. Beneath these old Paleozoics lie young Tertiary sediments, seen not only in outcrops but found in drilling to modest depths for metamorphic ore minerals. Additionally consider the increasing database showing relatively deep sediments in desert basins (a drill hole adjacent to the Sierra front near Olancha was still in sand at 7,000 feet, and a drill hole in Rose Valley near Dunmovin bottomed at 3489 feet in what is in all probability marine Tertiary sediments, and reportedly there are at least 14,000 feet of sediments in Indian Wells Valley, some of which is in all likelihood Eocene marine). If these sediments extend for miles to the west under the thin Sierran granitic sheet, the potential for oil and gas in this area alone is of major significance. In like manner, the potential for finding producible zones of petroleum source and reservoir rocks tucked in among complex stacked thrusts and beneath and within complex tectonic denudation sheets and lystral, fault blocks is a challenge the exploration industry should pursue with vigor.

3. Saline Minerals. As thrusts move out over valley fill, the accumulated salines can be buried to leave little or no surface evidence. With the voluminous sources for bitter salts reflected by at least 15 mineralization centers, the probability of hidden major deposits of borates and related bitter salts becomes attractive indeed. Thus there may well be saline bodies beneath the Argus range, and one can build a strong argument that a significant portion of the Searles Lake salines is beneath the thin granitic sheet just west of the present Trona complex.

4. Precious Metal Ores. All 15 of the mineralization centers shown in Figure 1 have the potential for associated epithermal ore deposits. Several of these areas are at or near pervasive zones of hydrothermal alteration. When one considers the various geometric possibilities it becomes obvious that not only can localized deposits form in such features as breccia pipes or fracture zones but linear traces of deposits can be formed as a thrust sheet moves over a deeper source. Prospecting targets will include depositional areas between thrust sheets, giving rise to repetitive zones of deposition both vertically and offset laterally due to fluid migration beneath a capping thrust. A target of unique interest could be boiling zones located immediately behind a thrust edge or a boiling zone created as a result in localized pressure reductions at sheet flexures.

5. Groundwater. Whatever else is done in the desert regions, water is the key to development. Just as the thrust sheet model for the eastern Sierra has dramatic implications for the estimation of groundwater recharge into the valleys bordering the Sierra, such models also sharply alter how one would predict both shallow and deep water movement with respect to

the advisability of particular locations for waste repositories or waste handling facilities.is also a major potential for massive amounts of Sierran inflow to the east, beneath the desert regions extending from the Sierra to the Colorado River. A careful evaluation of the three dimensional fracture geometry of this area including widespread thrusting could well show areas in the desert region where major supplies of groundwater are available at drillable depths. Locating such a supply could have a profound impact on the desert, whether leading to new industries or more significantly, to major new population centers.

The evidence for a complex compressional structural geology for the Sierra Nevada and the adjacent desert regions has grown to the point we feel it should not be ignored. Rather, industry and academia should abandon dogma and make a major new effort to evaluate this exciting region. When Norris and Webb stated in their textbook, "Geology of California"

> "The broad picture can elude the geologist presented with an abundance of well exposed detail."

they were criticizing the thrusting models being proposed for the Basin and Range east and south of the Coso region. Perhaps it is time that the abundance of well exposed detail be used to inspire a fresh look at the region.

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THE COSO GEOTHERMAL DEVELOPMENT—
AN EXERCISE IN MULTIPLE USE

by

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and

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Bureau of Land Management

INTRODUCTION

The primary purpose of this account is to demonstrate the long spans of time over which both personal commitment and agency policy must remain relatively consistent in order to achieve a new working concept. Such events do not happen overnight nor do they result from administrative fiat. Rather, they result from the efforts of individuals seeking to create a common goal, in this instance the production of geothermal power through the multiple use of a military weapons range, and by enhancing the ability of the range operators to perform their national defense mission while enabling private industry to do that which it does best the assumption of risk and the creation of new wealth through industrial development.

This story is not presented as a complete or definitive project history, although the events and dates presented are factual. Parallel efforts were often underway to achieve diverse project milestones, some activities are chronicled separately, thereby providing the reader with a better understanding of what had to transpire to keep the Coso project alive and progressing.

The reader should understand from the start that initially there was no Navy requirement for the Coso project. That is to say, The Naval Weapons Center (then the Naval Ordnance Test Station) was not ordered to create a geothermal multiple use project on its test ranges. Rather, the base devised the idea, and then set out to convince both the Bureau of Land Management (BLM) and more importantly, the military chain of command, that such a project was in the best interests of all parties concerned. Opposition was encountered Navy groups opposed the project as an intolerable encroachment onto Navy test ranges, BLM factions opposed the project as an intolerable encroachment into their leasing authority, industrial factions opposed the project as they did not wish to deal with the Navy; but when all is said and done compromise, negotiation, and common sense have prevailed to result in a "grand experiment" in multiple use; one that is working today.

Pre-Navy Events

Prior to the creation of the Navy test complex at China Lake in the early 1940's, the area, now referred to as the Coso geothermal area had a lengthy history of exploration, sporadic mining, and resort type development. This early history is detailed in a text prepared for the Navy, entitled "A Land Use History of Coso Hot Springs, Inyo County, California." This is the most detailed and definitive history that has been compiled for the area. Described in somewhat over-enthusiastic terms by M.H. Farly in 1860 as including an active volcano, the Coso area was originally shown on maps as "Hot Mud Bank", then as "Mud Spring" and in

more recent times as "Coso Hot Springs". On the other hand the small hot springs in the marsh comprising "Lagunita" have received little interest despite their being mentioned in early reports of the area published in 1876. Indeed, few people passing by Lagunita, now anglicized to Little Lake are aware of the fact that Little Lake is not a simple emergent underflow but is partly geothermal in origin and differs strongly in its chemistry from the groundwater of Rose Valley to the north.

Power production interest was expressed for the Coso area as early as 1925 when a report on the power potential of Coso was prepared for the Southern Sierras Power Company (now a part of Southern California Edison) by H.N. Siegfried (reprinted by the Geothermal Resources Council).

During the early development of the area there must have been a strong local faction interested in the Coso Hot Springs as this area was at one time briefly considered for a National Park. In similar manner, the therapeutic nature of the mud and waters was touted by local enthusiasts, a number of whom bitterly opposed the Navy taking jurisdiction over the springs area although it should be noted that the so-called hot springs area consists of over 40 shallow wells drilled by hot springs entrepreneurs prior to Navy acquisition, and there is no identifiable Coso Hot Springs per se. A letter to Eleanor Roosevelt illustrates this local interest and concern. This letter is given as Appendix A.

Navy - Pre Geothermal Project

With the arrival of the Navy, the small resorts and mines were purchased by the Navy in 1945 and closed to general public access. Figures 1 through 5 show various major structures as they existed in 1948. The two main resort buildings are still standing. The adobe building of Figure 3 is rapidly crumbling as the roof blew away a few years ago, exposing the walls to the weather. The King Mining mill of Figure 4 was sold in the early 1960's by the Navy and is now marked only by the tailings pile and the wooden loading ramp. The Lynch Mill is still essentially intact, much as shown in Figure 5. The arrival of the Navy essentially froze the Coso area in time, preventing most vandalism but allowing a steady decline owing to no maintenance.

The first two decades of Navy ownership of Coso in the form of acquired lands and withdrawn lands, saw little pressure for development of the thermal area. Occasional proposals were made to create a new resort complex or to drill for steam but none were pursued with any vigor until the late 1950's. With the advent of geothermal production at the Big Geysers Geothermal north of San Francisco, various entrepreneurial groups expressed more interest in the Coso area. In part this was due to the hope that the inability to acquire a title to steam on the public domain could be offset by dealing with the Navy.

The one group that actually fielded an exploration team at Coso in this early timeframe was Inter American Resources, a subsidiary of Keevil Mining of Toronto, Canada (now located in Vancouver, B.C.). The Keevil group, in cooperation with the Navy did detailed geologic work in the Coso's and a considerable amount of this work was made available in a 1964 Navy publication, "Coso Hot Springs - A Geologic Challenge".

The Navy involvement in the Coso geothermal area is commonly dated from this study, as it marks the beginning of serious efforts to determine the geothermal potential of Coso. However, this effort was not met with universal enthusiasm within the Navy, and dispute quickly erupted. This is clearly enunciated in a memo from the NOTS Plans and Operations Officer to the NOTS Associate Technical Director dated 11 February 1964. This memo stated:

a. After considerable discussion Doc Austin arrives at the conclusion that the Coso thermal area offers an excellent steam potential. The conclusion is in conflict with a Geological Survey report "Coso Hot Springs as a Possible Hydrothermal Power Site" by W.R. Moyle, Jr., 1962. Mr. Moyle, working for the Water Resources Division of the Department of the Interior, submitted his preliminary report to us for review in August 1962. His report would discourage, rather than encourage, commercial exploitation of Coso Hot Springs. In other words, Moyle said that the steam has little or no commercial value. We imposed no objection to his report and understand that it should be out shortly.

b. Other NOTS geologists do not agree with Doc Austin,s conclusions."

Thus the debate within the Navy at China Lake was well joined, with Dr. St. Amand of the Earth and Planetary Sciences Division, with the support of the U.S.G.S. opposing the study and possible development of Coso and Dr. Austin, head of the Petrodynamics Branch of the Detonation Physics Division supporting the study and possible development of Coso.

The availability of data on Coso took a major step forward with the drilling of a test well (Navy Coso No. 1) in 1966 and 1967. This well, located in the resort area north of the main resort buildings, gave invaluable data on the chemistry of the apparent brines by encountering chloride brines (no chloride brines were known at Coso prior to that time) and by providing a calculated reservoir temperature estimate of 415°F, both highly encouraging and verified by production drilling in 1981 and 1982.

Geologic studies continued, with the Navy encouraging university students (Fergurson, UCR) and then with first a Navy funded ground noise study followed by extensive heat flow drilling and geophysics funded by DARPA, with the assistance and foresight of Rudy Black of DARPA providing encouragement at a critical time.

Following this line of thought a little farther, significant data was provided by follow-on studies by Pacific Northwest Laboratories (PNL), an Energy Resource Development Administration (ERDA) (now DOE) laboratory, who conducted a drilling technology and hot dry rock experiment at Coso from 1975 to 1977. This study, though highly controversial at the time, proved commercial steam-flow rates and temperatures near the crest of the Coso "anticline" west of the old resort area.

Although the Naval Weapons Center in effect formally increased its interest in the geothermal program significantly in 1971 with the publication of "Geothermal Science and Technology A National Program" by Austin, Austin and Leonard, the program did not become an organizational entity until 1977. At this time the project plan widely referred to as the "Box Briefing" was devised by Dr. Austin, Capt. Daniel (the Public Works Officer) and Cdr. Cowell (the legal officer). This three-phase program was designed to: (a) protect the Naval Weapons Center mission, (b) provide alternate energy, and (c) provide a savings in energy costs with the minimum acceptable goal being to protect the mission from energy driven encroachment. This program allowed for both ERDA/DOE development as a demonstration project and geothermal leasing by BLM under the Geothermal Steam Act in addition to development by the Navy. It is this program that is still being pursued today, jointly by both the BLM and the Navy. This joint effort has brought to focus years of dialogue between Navy and BLM, starting during the tenure of J.R. Penny as state BLM director.

In the early dialogue with the BLM, the BLM was adamant that any development of geothermal resources at Coso would have to be done by BLM, ignoring the fact that under Public Land Order (PLO) 431, the BLM did not have any authority to conduct such an activity. The Navy was equally adamant that the Navy would retain jurisdiction over all surface and airspace on the base and would proceed with its own development contract. Relations deteriorated with the Regional Solicitor for Interior finally informing the Navy that Interior

would cite the Base commander and Dr. Austin, the Navy geothermal project manager, for trespass if the Navy persisted in its development efforts. The debate became 3 cornered when Mineral Management Service (MMS) argued for an exploration unit at Coso, to be based on acreage while the Navy took the position there would be no unitization until production was proven and MMS disputed the Navy right to its own drilling activities as well. The Navy response to these issues was to place a rider on the 1978 Military Construction Authorization Act which provided the authority for the Navy to proceed with its development contract on acquired lands. The Navy further clarified its position the following year, gaining authority for contracting on withdrawn lands as well. These two legislative actions are now Title 10, U.S. Code Section 2689.

During this same general time frame, Dr. Austin drew up maps apportioning the Coso area into fee lands (Navy), reserved withdrawn lands (for Navy) and lands to be released to Department of Interior for leasing under the geothermal steam act, given a modification of PLO 431, which created the north ranges.

Agreeing to modify PLO 431, was probably the most difficult Navy decision to achieve, involving a great deal of soul searching with respect to future risks such a change would create for the weapons ranges. It was recognized in both BLM and Navy that to do a BLM leasing project within the Base would require allowing BLM some degree of control over leasing activities within an active military weapons range (albeit limited essentially to subsurface authority) and that an entire host of new working relationships would have to be devised regarding both on-lease activities and off-lease activities within the base. The decision within the Navy was to proceed, and from this point onward, Coso has been truly a joint Navy/BLM effort and the change in PLO 431 was accomplished at the Washington level with relative ease.

Critical to making this joint effort actually work was the creation of a "constraints package" which spells out the aims and goals (first part) and defines the working relationships (second part). The creation of these two agreements, devised at the local working level, was the sine-qua-non for proceeding. These are presented in appendices B and C in their entirety. Making these agreements work is a continuing effort - there are no precedents, and changing personnel creates a constant need for education in both the BLM and the Navy as to "how we got here" and "where we are trying to go."

In a nutshell, the Navy is the surface and subsurface manager for all of the Navy geothermal contract development. The Navy is the manager for all off lease activities by anyone within the NWC boundary. On the BLM leased lands the Navy is the surface manager with the BLM the subsurface manager with some joint surface management relationships to ensure lease activities both conform to BLM standards and are consistent with Navy requirements. This is well illustrated by the fact that the Commander NWC is responsible for the safety of everyone on the base, including BLM personnel and BLM leaseholders.

To help leaseholders and their operators cope with this duality of management, the Navy and BLM have devised the procedural flow chart of Appendix D which on examination can seen to be quite similar to the procedures for conducting geothermal lease operations on U.S. National Forest lands.

As we have observed in practice, the main problem we have encountered with groups within the Naval Weapons Center boundary is the dismay expressed by them on finding that the Navy closely and continually inspects all activities for safety and compliance with both Navy and BLM rules and regulations. This is because unlike activities on BLM land, the Base Commander is personally responsible for all activities within his base, a responsibility that is real and pervasive.

Conclusions

In our opinion, this grand experiment in multiple use has worked remarkably well to date. The Navy contractor has constructed 3 turbines under the contract and has 80 megawatts on line.

Much more important, not only were the lease sales at Coso eminently successful in terms of bonuses bid, the first leaseholder is also on line with his three initial turbines now being built, and two of them in actual production. We feel that this shows beyond a shadow of a doubt, that the constraints package is realistic and workable, and the joint management effort of the BLM and Navy is both workable and understandable.

Of national importance, the mission of the Naval Weapons Center has been protected and secure energy been made available for the overall conduct of the NWC mission. As we continue to set new working precedents, the Navy at NWC and the BLM at the Ridgecrest Resource Office and the Desert District offices take great pride in having created and placed in operation a multiple use project on a military weapons range.

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F I G U R E S

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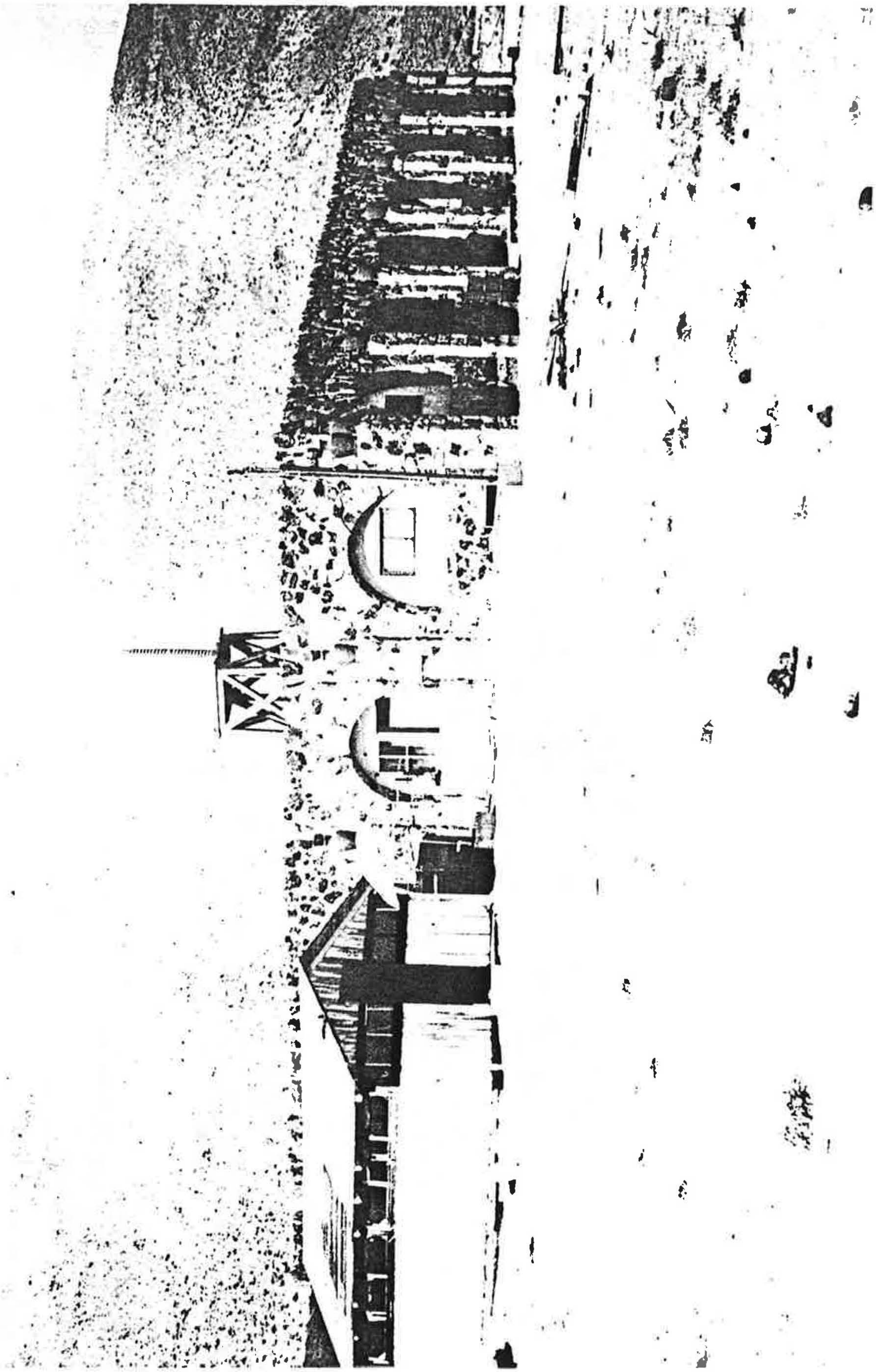


FIGURE 1. The Main Resort Building, That Housed Office, Lounge and Cafe at the Coso Hot Springs.

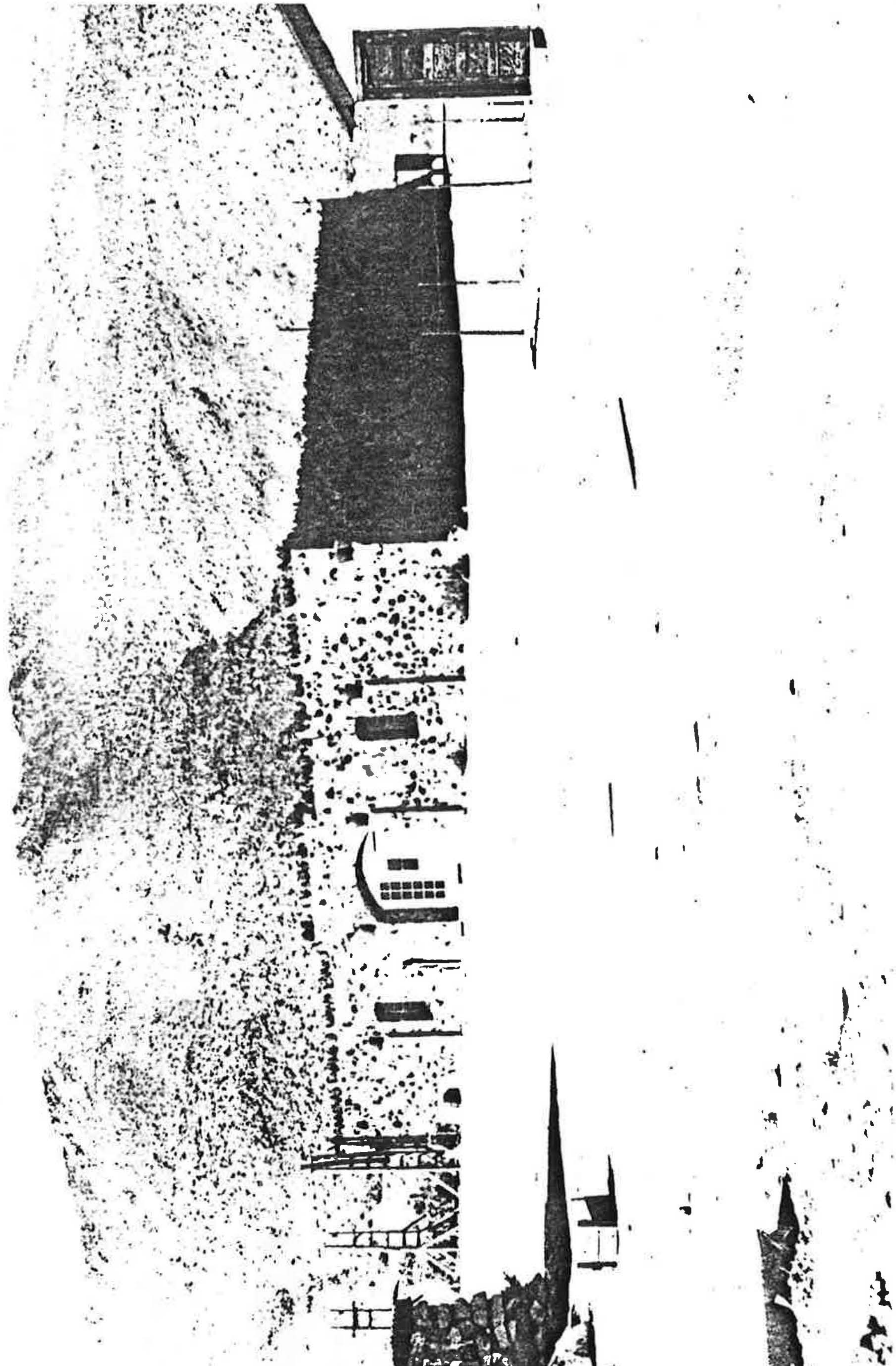


FIGURE 2. The "Bottling Works", Taken in 1948 at the Main Resort at Coso.

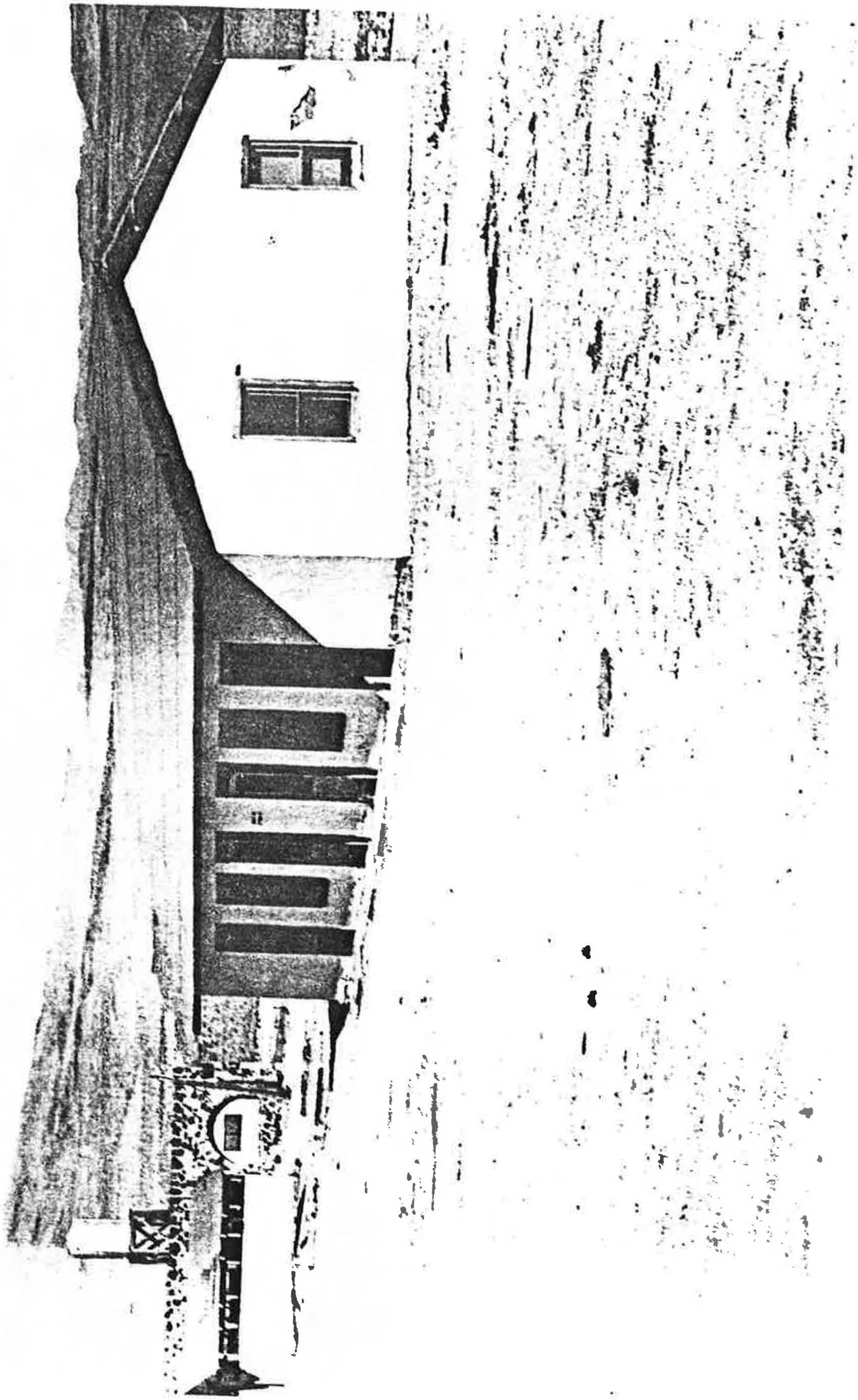


FIGURE 3. Adobe Structure, in 1948,
Now Largely in Ruins.

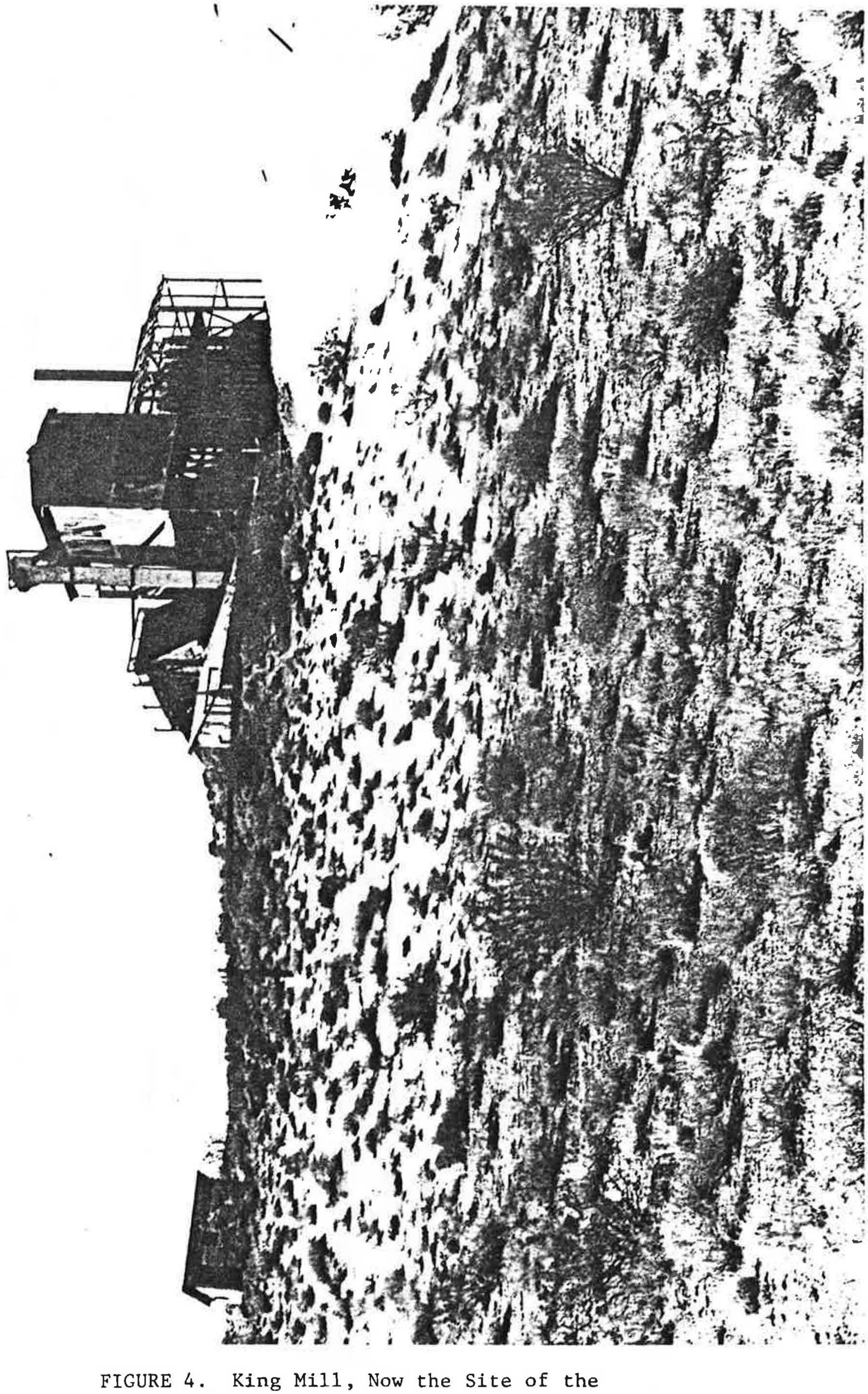


FIGURE 4. King Mill, Now the Site of the 80 Megawatt Navy 1 Power Plant, Photo Taken in 1948.

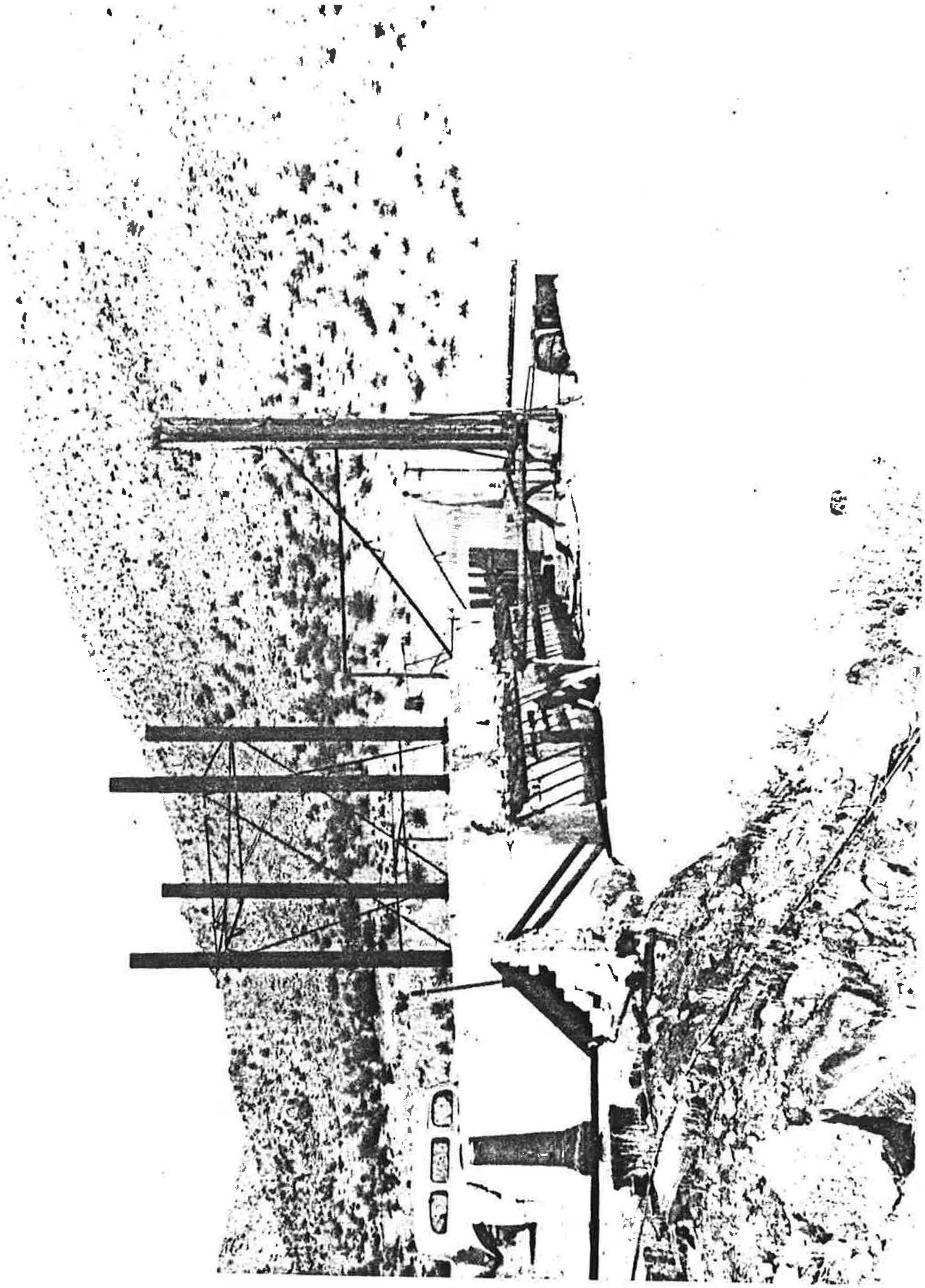


FIGURE 5. Lynch Mill in the Coso Geothermal Area, 1948.

A P P E N D I X   A

COPY

Little Lake, Calif.
Mar. 23-45

Dear Mrs. Roosevelt,

I am writing you in person in behalf of all the sick people that go to Coso Hot Springs and are cured of arthritis, ulcers of stomach, and venereal disease and many other diseases; every year. Now we have an epidemic of Infantile Paralysis at the New Navy Base at Inyokern, Calif. which I am quite sure could be cured at Coso.

I am going to write to you as I would talk to you. The Navy is taking over Coso Hot Springs to use as a bombing area. Why? With all the thousands of acres of desert country, do we have to give up our place of cure. It is the same to us people of this part of the West as warm Springs, Georgia, is to our President. My present husband has worked all over the world in every country, for Westinghouse people and he will swear it is the only springs in the world like it.

I do wish you would send some one, if you can't come yourself and investigate it, to see it's real worth.

I was married to a Navy Officer for 16 years. Spent two years in Guam, contracted, a tropical worm in the bowls, had ulcers in my stomach and intestines, was on the verge of Prenicious anemia. I was thoroughly examined under medical group of 14 Dr. and told I had to have my stomach out most away and 12 ft. intestines; also my bowels must be operated on. I really only had 1 chance in 10,000 to live thru the operation as ulcers were almost thru the stomach. I was given 1 month to build up for operation. I left the hospital and came to Coso Hot Springs and was cured in 1 month; that was 14 years ago and I have never had a return of the ulcers. I was given a lead coated pill to kill the worms in my bowls. I believe it contained a worm poison.

I have also had arthritis; where I would have been a cripple for life and went there and cured myself in 8 weeks of baths - I am 48 years old in May.

My husband is 84 in August He has medical group's give him up time and time during the last World War he fell in the shipyard and jammed his tail bone up like a letter S on the end. The Dr's kept him in hospital 18 months and tried everything finally putting him in a wheel chair for life; to wear a cast, also. He went to Coso Hot Springs and in 6 weeks he cut his cast off and in 10 weeks he could walk in 3 months he could stand flat footed on the floor

jump on a Dr's office desk - ride horseback and hike the hills. He has had a bad heart, crushed between a boat and dock in a bad storm, he fell overboard. That was 20 years ago. He is still vigorous and has built himself quite a large house of pumice brick in the last 4 years. He built his house at Coso Hot Springs to live the rest of his days there.

Not Mrs. Roosevelt, for the sake of all the sick people here please won't you investigate before the Navy bomb it and ruin it for health purposes. I'm sure if you could hear testimony from more people you would really believe, my husband and I also know a man that was in the last stages of syphillis, his meat was dropping from the bone that went to Coso and got cured - There are 14 different minerals in the mud hole there, an extinct volcano. It is still hot and boiling, mercury and sulphur predominating.

Perhaps the Government would take it over for returning soldiers. Its such a terrible thing to use a wonderful place like that as a bomb range and close it altogether. It really should be run by the Government and build a suitable hospital or cabins there and put responsible parties in charge.

I do sincerely hope you or our President will not let this go by without a real investigation.

I am sincerely, one who has suffered tortues of pain and sickness for years and am now in the very best of health and going 2 mens work every day besides mothering 3 husky boys at home and have a daughter doing red cross work and a son in the Navy.

Just one of many thousands thats received a cure.

/s/ Mrs. Lauretta Ball

P.S I am enclosing one of the folders from the Springs. It gives a full analysis of water and mud.

P.S.S. In bombing so near the springs it will perhaps cause a shutting off of the water and steam in breaking the earths crust.

L.B.

APPENDIX B

Appendix C

C.1 MEMORANDUM OF UNDERSTANDING
Between
Naval Weapons Center, Department of Navy
Bureau of Land Management, Department of Interior

GEOTHERMAL LEASES IN COSO GEOTHERMAL AREA

It appearing that the Secretary of the Interior, acting through the California State Director, Bureau of Land Management (BLM) and the Department of the Navy, acting through the Commander, Naval Weapons Center (NWC), China Lake, California, have a mutual interest in certain real estate involving both acquired and/or withdrawn lands lying within and without the boundaries of NWC, and being generally within the sub-surface to a circular surface area of a diameter of approximately forty-two (42) kilometers and centered at approximately 36° 05' latitude and 117° 50' W. longitude for the production of geothermal steam and associated geothermal resources. This area is depicted on the attached plat;

And it further appearing that although approximately the eastern sixty percent of this area lies within the boundaries of the NWC and, therefore, the surface of the area is under control and administration of the Department of the Navy, through the Commander, Naval Weapons Center; and that approximately the western forty percent of this area lies outside the boundaries of the NWC and, therefore, under the administration of the Department of the Interior, through BLM;

And it appearing that expeditious development and exploitation of geothermal steam and associated geothermal resources is of great importance to the United States, its agencies and its people;

And it also appearing that such development can be accomplished only with the highest degree of cooperation between the two governmental agencies which are parties hereto;

And it appearing that the NWC is an irreplaceable facility essential to the Navy in fulfilling its National Defense responsibilities;

And it appearing that it is in the National interest that there be orderly, optimum and expeditious development and expolitation of geothermal resources in the Coso area in such a manner that the NWC may continue to perform, fully, its National defense functions;

Therefore, it is deemed appropriate that this Memorandum of Understanding be entered into between the parties and their designated officials;

This Memorandum records the understanding of the parties as follows:

1. Public lands withdrawn for the purpose of the NWC defense mission shall be available for geothermal leasing upon NWC's written consent thereto with those stipulations determined necessary to make geothermal operations compatible with the mission of NWC. BLM will, to the extent authorized by applicable law, commit withdrawn lands within NWC to leases in accordance with mutually agreeable schedules.

2. NWC will proceed with its geothermal exploration and development program on acquired lands in the above-described area to provide a secure power supply for the Navy and to gain Navy expertise and experience in employment of this new energy source for support of military missions.

3. NWC and BLM shall cooperate in obtaining modifications to the applicable Public Land Orders to permit the leasing and development of geothermal resources on those lands described above. Jurisdiction over the subsurface and surface of NWC lands covered by this Memorandum necessary to permit development and exploration of the geothermal resources will be vested in the Secretary of the Interior, subject to such surface use controls and/or contraints as may be stipulated by NWC.

4. BLM agrees to coordinate lease stipulations for the public lands in proximity to the NWC lands with the Navy in consideration of the Navy's mission at NWC.

5. The parties agree to immediately take steps to determine methods under which NWC lands can legally be leased and to set forth schedules and programs for completing environmental analyses, leasing schedules, and methods of lease supervision and management of NWC lands, together with mutually acceptable lease conditions on adjacent public lands. Control of access, supervision of operations and handling of data shall be developed as part of lease terms and future agreements between the involved agencies. Lands within the NWC withdrawn area will be withheld from leasing until appropriate terms for development, utilization, or management are approved by the Navy.

6. In general, BLM and NWC agree to fully support each other in this mutual effort, and specifically, to support each other as necessary to accomplish the fullest development of the resource. BLM and NWC agree to cooperate in the development of terms and conditions which will enable lessee operations and NWC operations for exploration and production of geothermal resources in a compatible manner, including but not limited to, utilization, procedures and/or joint development.

7. It is mutually understood by BLM and NWC that the Commander, Naval Weapons Center does not have quthority to fully implement this agreement and that NWC will expeditiously request that authority.

8. It is mutually understood by BLM and NWC that the surface use controls and/or constraints will be identified per paragraph 3, within approximately 60 days of the the execution of this agreement. Those stipulations will then be made a part of this MOU by amendment. It is further understood

that after the initial 60 day period, any emerging control/constraint necessary to prevent an adverse impact on the NWC mission will be incorporated into the BLM leases.

DATED: Dec. 6, 1977 W. L. Harris

Commander, Naval Weapons Center
China Lake, California
DEPARTMENT OF THE NAVY

DATED: Nov. 30, 1977 Ed Hastey

State Director, Bureau of Land Management
California
DEPARTMENT OF THE INTERIOR

A P P E N D I X   C

AMENDMENT TO
MEMORANDUM OF UNDERSTANDING
Between
Naval Weapons Center, Department of Navy
and
Bureau of Land Management, Department of Interior

GEOTHERMAL LEASES IN COSO GEOTHERMAL AREA

Pursuant to paragraphs three and eight of the Memorandum of Understanding between the Naval Weapons Center, Department of Navy, and the Bureau of Land Management, Department of Interior, executed on 6 December 1977, it is jointly agreed by the undersigned that the following Navy constraints of geothermal operations on Naval Weapons Center lands will be incorporated into the Memorandum of Understanding.

1. General.

Constraints will be placed on geothermal operations within the boundaries of the Naval Weapons Center to ensure the safe and economical development and production of those geothermal resources within the NWC boundary and to ensure that any leasing, development or production does not conflict with the mission of NWC. In addition to the lease terms and requirements contained in the lease form, the lessee shall comply with the following special stipulations unless they are jointly modified by the Commander, NWC and the State Director, Bureau of Land Management, with concurrence of the USGS Area Geothermal Supervisor.

2. Administrative Responsibility.

The Commander, NWC, is the responsible agent of the Federal Government for the utilization of the land surface and airspace of NWC. As such, the Commander, NWC, is responsible for the protection of the health and safety of all personnel, military and civilian, within the confines of NWC, and is responsible for the continuing preservation of the ability of NWC to perform its mission of air delivered weapons research, development, test, and evaluation.

3. Access.

Access to the NWC is a privilege granted by the Commander, NWC. Exercise of this privilege requires adherence to NWC traffic regulations, check in/check out procedures, radiation control measures, environmental controls, area access limitations, and electronic emission controls and such other published administrative regulations as appropriate. Access shall be on a not-to-interfere basis with NWC test schedules, and shall be limited to that specific lease block or area being explored, developed or produced. Access schedules shall be established on a weekly basis with NWC. NWC shall provide uninterrupted short term access for reasons of geothermal safety or other drilling incidents requiring access to a specific site for geothermal operations. Experience to date shows that in any given month, scheduled and unscheduled daylight downtime will not regularly exceed 10% and nightime downtime will not regularly exceed 2%. Access shall require that for each lease holder, one

responsible contact point shall at all times know who is present on NWC lands, and this contact point shall be reachable at all times in event evacuation is ordered.

4. Security.

The mission of the NWC is such that visitors cannot be granted access to NWC lands without going through NWC security procedures. All non-citizen visits must be arranged through NWC with a minimum notice of 96 hours for non-communist-bloc visitors. The latter will be considered on a case-by-case basis. Accessible areas visitors use will be delineated by NWC.

5. Environmental.

NWC retains the right to suspend any operation judged by the Center to present an imminent threat to the environment. During all operations, all federal, state and local environmental standards shall be rigorously observed. No components of the environment shall be unnecessarily disturbed. NWC shall have the right to impose those emission standards required to protect the Center's mission.

6. Sites and Routes.

All vehicular traffic shall be limited to routes approved by NWC. Power plant sites, drill pad sites, and pipe line routes will be selected subject to NWC approval to ensure that such sites will have a minimum impact on NWC range operations. All site plans shall be submitted to NWC for review and approval. Routes to and from work areas within lease blocks shall be approved by NWC.

7. Shelters.

Lease operators shall have the option of either moving employees outside NWC boundaries upon request of the designated representatives of the Commander, NWC, or retiring to NWC approved personnel shelters provided by the lessee during those times when the NWC operations require personnel protection at the work site.

8. Radioactive Sources.

No radioactive sources shall be brought into NWC until appropriate Navy permits have been obtained. These permits will be issued after NWC has verified the license of the operator to be valid for the proposed effort and has approved written standard procedures for use and for handling lost or damaged sources.

9. Injuries and Accidents.

All disabling injuries occurring within NWC boundaries will be reported within 24 hours to NWC. NWC will have the right to suspend any operation judged by NWC to present an imminent danger to any personnel on NWC property or to government property.

10. Electronic Radiation.

Electronic emissions will not be permitted without prior review and authorization by the NWC. Periods of emission will be coordinated with the Center and, at times, the Center may require electronic emission silence for periods of up to four hours.

11. Plant Protection.

All well-heads shall be revetted to a degree acceptable to NWC; all wells so designated by NWC shall be fitted with an approved below ground or revetted flow limiter; all pipe lines shall be fitted with automatic flow limiters as approved by NWC and all power plants shall be equipped with a hardened control room approved for continuous occupancy during NWC tests.

12. Information.

All information on incidents involving both NWC equipment and/or personnel and the geothermal operators will be released to the public jointly by NWC and the Department of Interior. Particular attention will be given to information concerning incidents that have the potential for high public interest. Any serious injury or fatality and any geothermal blowout will be reported at once to NWC.

13. Military/Government Property.

All military and government property found on the land surface or embedded in the land shall be left in place. NWC shall be informed of the presence of all suspected or potentially hazardous material immediately and NWC personnel will inspect and remove such material in a timely manner. In case of doubt, NWC is to be called for an inspection.

14. Data Exchange.

Data on flow, chemistry of fluids and reservoir conditions and structure shall be provided to NWC with such data to remain proprietary in accordance with current practices and procedures as developed by the Area Geothermal Supervisor and set forth in 30 CFR 270.

15. Legal Jurisdiction.

Law enforcement on NWC lands will remain the responsibility of NWC. The use of geothermal operator employees in a guard function or the contracting by the geothermal operator for security guards on NWC lands will be subject to review and approval by NWC.

16. Right of Inspection.

NWC shall have the right of inspection at all times to ensure and verify compliance with these constraints.

Dated: 8 July 1980

W. B. Haff

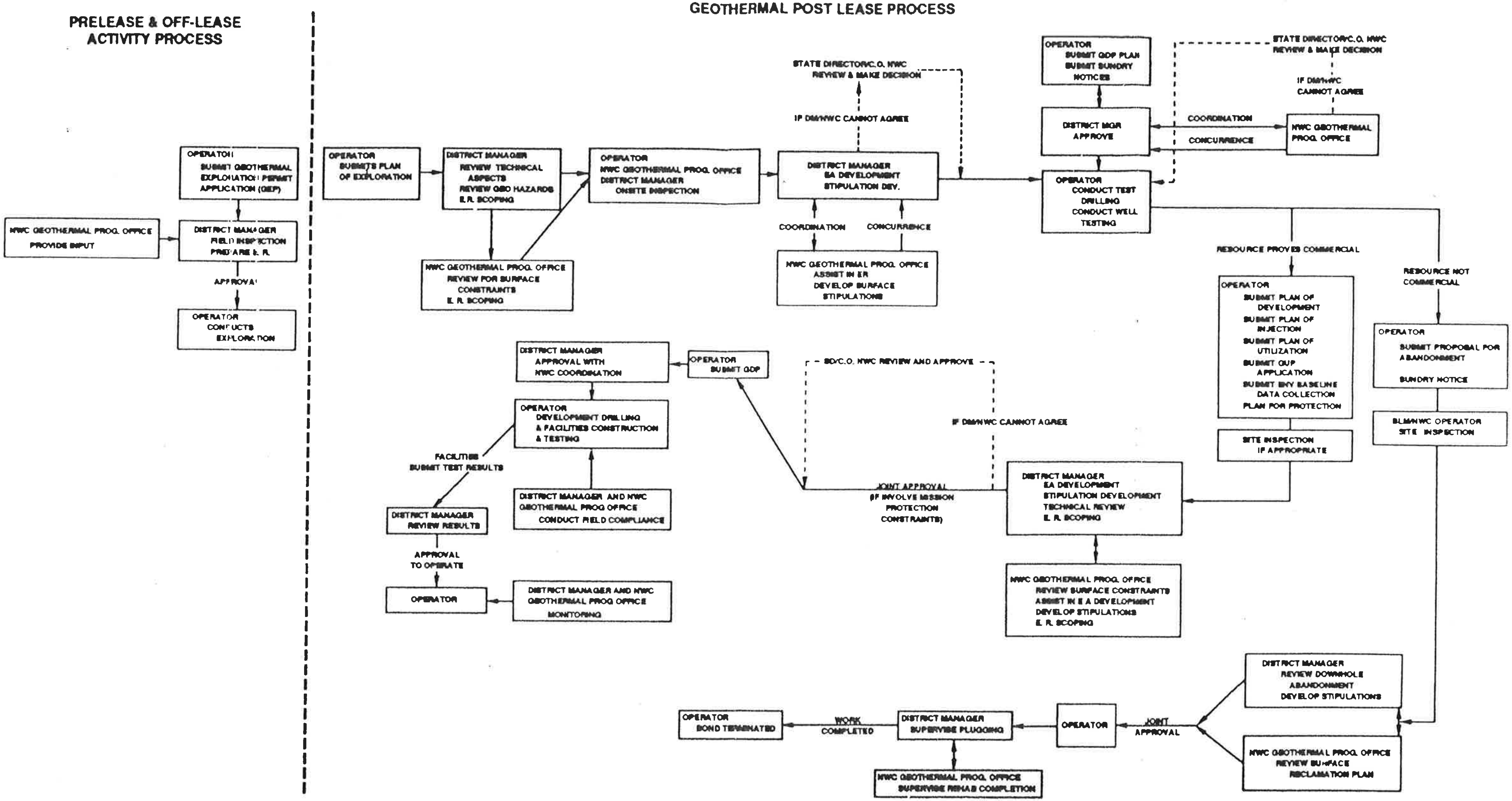
Commander, Naval Weapons Center
China Lake, California
DEPARTMENT OF THE NAVY

Dated: 8 July 1980

State Director, Bureau of Land Management
Sacramento, California
DEPARTMENT OF INTERIOR

APPENDIX D

NWC GEOTHERMAL DEVELOPMENT LEASE APPROVAL/ADMINISTRATION PROCESS



MODERN AND ANCIENT GEOTHERMAL SYSTEMS IN THE CALIFORNIA DESERT

Their scientific and technological significance to our energy and mineral wealth

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Much of the energy and mineral wealth of the California Desert is intimately linked with modern and ancient geothermal systems. Understanding and appreciating the genetic and technological aspects of these links is vital to the efficient use of our natural resources.

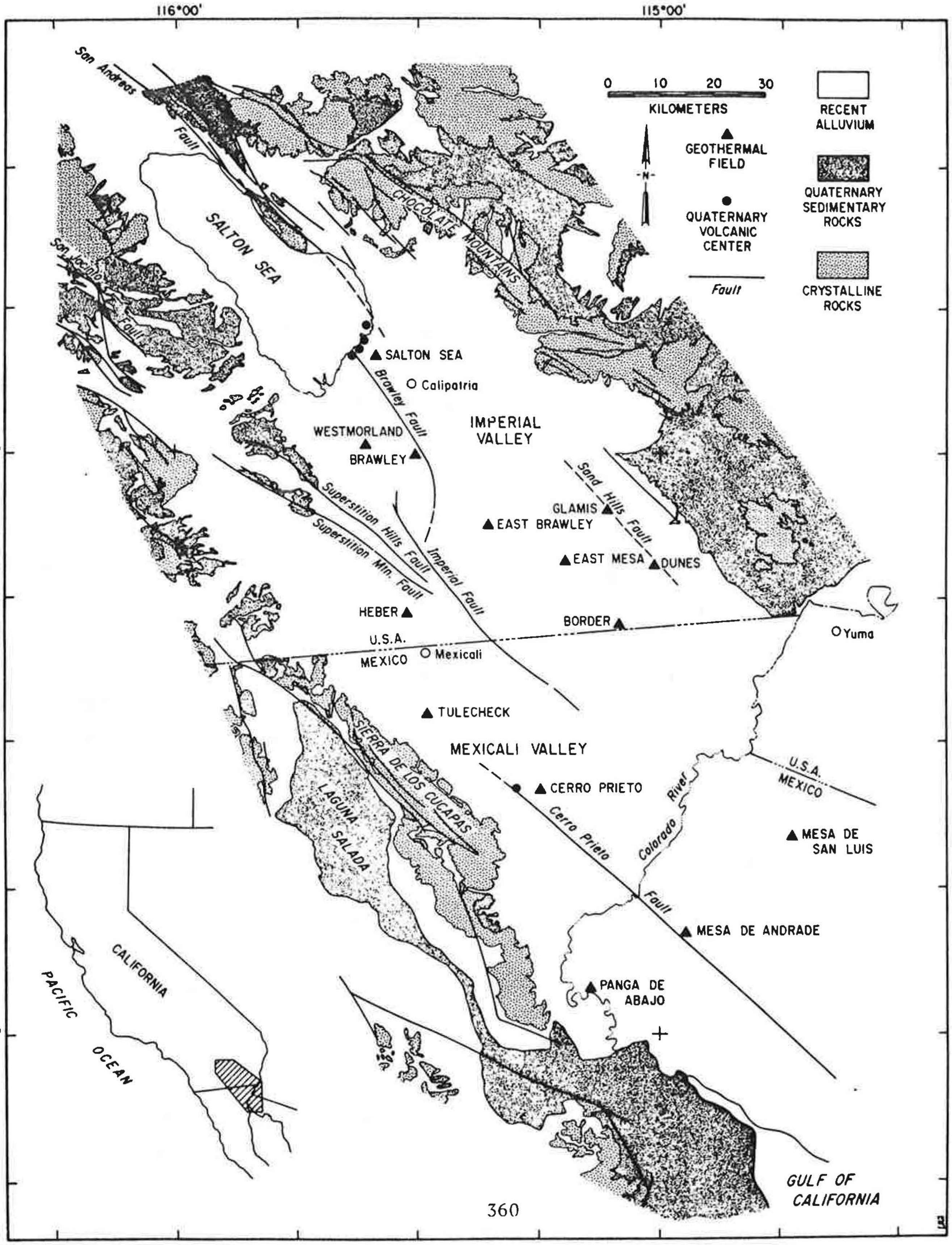
Modern geothermal systems

Modern geothermal systems are increasingly important sources of electric power and heat, and may also have potential as sources of byproduct chemicals. The Salton Trough of southern California and northern Baja California (Figure 1) is probably the best–known geothermal resource area of the California desert (Elders, 1979). The Cerro Prieto geothermal field in Baja California (Lippmann and Manon, 1987) has 640 MWe installed geothermal power capacity, the world's largest capacity outside of the Geysers field in northern California. Geothermal development in the Salton Trough north of the border has been slower for environmental reasons. However, the Salton Sea geothermal field is now undergoing rapid commercial development and will soon have approximately 200 MWe of installed capacity. The highly saline Salton Sea geothermal brines require use of a unique multi–stage flash reactor–clarification system. The brines in this field are also laden with economically valuable elements such as Li, Mn, Zn, Pb and Ag, whose recovery in the future may become economic as byproducts of geothermal power production. The nearby East Mesa geothermal system, with lower temperatures and salinities than the Salton Sea field, will eventually have about 75 MWe of installed production capacity using a two–stage flash system. Other desert geothermal areas outside of the Salton Trough under development include the Coso geothermal area, located in the southern Owens Valley, which will soon have an installed capacity exceeding 200 MWe.

Ancient systems

Many of the mined Au, Ag, B and Li deposits in the California Desert are now recognized to be the products of ancient geothermal systems. Au mines such as Mesquite and Picacho in southeastern California (Liebler, 1988; Willis, 1988) are the products of low–salinity geothermal systems associated with extensional tectonics, and may have formed in

Figure 1. Map of the Salton Trough of southern California and northern Baja California, showing the location of active geothermal areas. From McKibben and Elders (1985).



environments similar to the modern East Mesa and Dunes geothermal systems (Bird, 1975; Hoagland, 1976). On the other hand, rhyolite volcanic–associated Au deposits such as Castle Mountain in the eastern Mojave (Ausburn, 1988) have strong similarities to the Coso geothermal system. The recent discovery of Au in some of these modern geothermal systems strengthens these comparisons.

Many industrial mineral deposits in the Mojave desert also have geothermal connections. The tremendous B deposits at Kramer (Siefke, 1985) and the unusual Li smectite deposit at Hector (Guerre, 1989) most likely formed in lacustrine playa settings fed by thermal springs. Further geochemical studies are needed to reconstruct the geothermal systems responsible for these valuable deposits, with the payoff of providing useful exploration models.

Role in exploration

Exploration strategies for many hydrothermal mineral deposits rely on studies of geological and geochemical processes in modern geothermal systems. Rock associations, hydrothermal alteration patterns, metal transport mechanisms, and geochemical anomalies in active geothermal systems are increasingly being used to develop mineral exploration models. For example, specific shallow geothermal features such as sinter deposits, acidic alteration, silicification, and oxidation are becoming important criteria in the search for epithermal precious metal deposits.

On a larger scale, modern examples of tectonic rift zones with closed internal drainage such as the Salton Trough contain diverse types of geothermal activity similar to those which appear to have formed a variety of valuable mineral deposits in the geologic past (McKibben et al., 1987, 1988). These include epithermal gold deposits, sediment–hosted massive sulfide deposits, salt and gypsum deposits, and bedded iron–manganese deposits. Potential fossil analogs include the Proterozoic McArthur Basin in the Northern Territory of Australia, the site of many valuable mineral deposits (Muir, 1983). Studies of modern rifts in the California desert can thus provide a tectonic framework for regional exploration of their fossil equivalents.

Technological interfacing

The potential for interfacing mining and geothermal technology has not yet been fully explored and exploited. Because geothermal areas are concentrated in plate boundary regions that have been subjected to long–term tectonism and volcanism, many geothermal systems in California occur close to major mines and mineral deposits. Thus, the potential exists for linking technologies between proximal geothermal and mining activities. For example, low–temperature geothermal fluids are being tested in heat heap leaching circuits in Nevada, dramatically increasing the rate of metal leaching (Trexler et al., 1987). Use of geothermal fluids for local plant power generation, space heating and process water can also cut mining costs.

Mineral processing technology can also be applied to geothermal problems, such as recovery of byproduct metals from the brines and sludges produced during electric power generation from saline geothermal systems. Besides improving the economics of geothermal power production, such metal–stripping could decrease the environmental hazards associated with disposal of geothermal brines and sludges.

It is important to realize the geothermal legacy of the mineral wealth of the California Desert. Recognition of the role of geothermal processes in ore genesis can yield new insights relevant to future exploration and development. Equally important to our future is the creative linking of geothermal and mining technologies, enabling more efficient and conservative use of our valuable energy and mineral resources.

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AN INTERPRETATION OF MICROSEISMICITY IN THE COSO RANGE, CALIFORNIA

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INTRODUCTION

The characterization of rapid extension along block faults (Roquemore 1980) high seismicity (Walter and Weaver, 1980) and young volcanic rocks and fumaroles (Duffield et al., 1980) in the Coso Range support the initial contention that local geothermal development may be possible (Austin et al., 1971). The Coso Range is currently providing steam for a 32Mw power plant and two additional plants are nearing completion. Because the Coso Range is currently under geothermal production it provides a test bed for multiple geothermal development models. The microseismicity in the Coso Range provides information on neotectonics, current stress patterns, and seismically active faults that are all very useful tools for geothermal exploration. This paper presents an interpretation of local microseismicity patterns in the Coso geothermal reservoir. These patterns include clusters of seismicity that are seen in cross section as near vertical cylindrical shapes that could be related to volcanic processes. Preliminary investigation of the microseismicity provides useful insight to the occurrence of producible geothermal resources. If the interpretation of microseismicity patterns, as an exploration tool, proves useful in the Coso Range, then a similar analysis may be considered for other areas within the region that have high seismicity and a similar tectonic environment, but are as yet unexplored for geothermal resources.

QUATERNARY GEOLOGIC FRAMEWORK

The Coso Range, with a history of Quaternary volcanism and tectonism, is in the southwest corner of the Basin and Range physiographic province (Figure 1). The Coso Range appears to be located within a zone of transition between two structural styles (Wright, 1975; Roquemore, 1980). The eruption of high silica rhyolite occurred at least 38 times over the last million years, and basaltic eruptions ceased only 30,000 years ago. Duffield, et al., (1980) have shown that about 35 cubic kilometers of lava have erupted during the last 4 million years. The Coso Range has been broken by Basin and Range extensional faulting and faulting influenced by right-slip on the San Andreas fault. The resultant structure is represented in the prominent horst and graben development on north-south trending faults and right-slip displacement on northwest trending faults. Bacon (1982) has shown that the eruption of both basalt and rhyolite in the Coso Range has been controlled by regional tectonic extension.

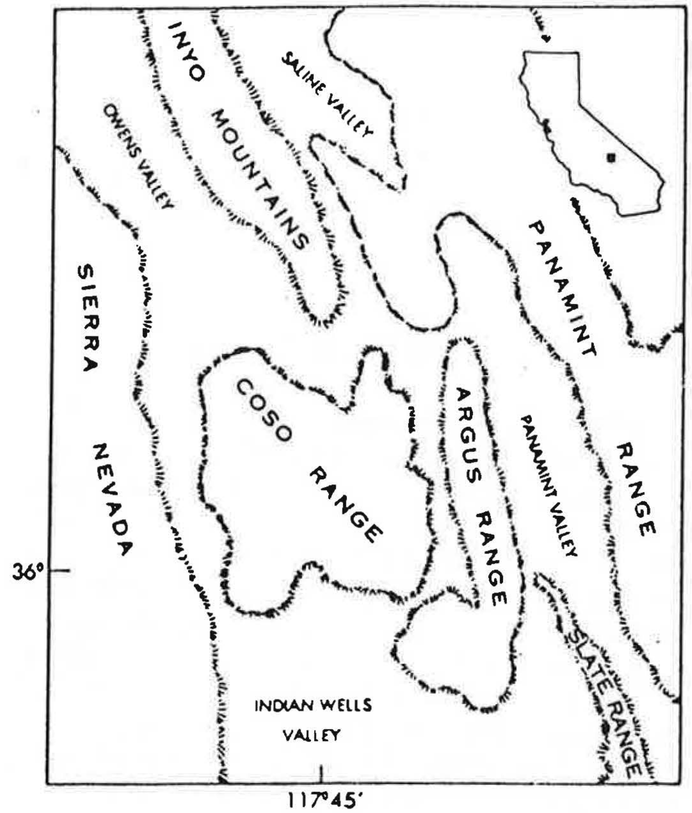

Figure 1. Index map showing location of the Coso Range and adjacent areas. From Duffied et al., 1980).

LOCAL SEISMICITY

The Coso Range and adjacent areas are within a seismically active region. Since 1975 there has been, on the average, about 4,500 recorded earthquake events per year, with the magnitudes ranging from M 1.0 to M 4.5. The first evaluation of seismicity in the Coso Range is by Walter and Weaver (1980) who, in two years, catalogued 4216 local events. Additional work in the Coso Range includes using seismic tomography methods to indicate regions with shown high-attenuation anomalies which could be interpreted as local magma bodies (Sanders, 1984, Walk and Clayton, 1987), the analysis of an unusual seismic episode that could be related to volcanic earthquakes (Given et al., 1983), and the analysis of focal plane solutions to characterize the neotectonic framework (Bent, et al., 1986). All of this work supports the existence of a tectonic, volcanic and seismologic environment that is conducive to the presence of a geothermal resource as recognized in other geothermally active areas.

During a study of the neotectonics of the Coso Range (Roquemore, 1980) the seismicity patterns published by Walter and Weaver (1980) were analyzed to identify seismically active faults within the rhyolite dome field. Active faults with clear geomorphic expression are common in parts of the Range but are not seen within a centrally located horst that contains the rhyolite dome field; the area of greatest geothermal potential. A series of cross sections were made through the dome field to view the hypocentral distribution of earthquakes along faults. The analysis did not reveal planar distributions in the dome field, however, faults outside of the dome field were identified. Within the dome field, dense clusters of earthquakes are aligned along nearly vertical cylindrical shapes that extend from within 1.5km of

the surface to a depth of about 5km. The hypocentral location of earthquakes between the clusters are generally dispersed and not assignable to any particular structure. Also seen in the hypocentral distribution is a deepening of seismicity to the north and south of the dome field that outlines a pronounced lack of seismicity below 5km, directly under the dome field. The seismicity found in clusters is of very low magnitude as compared to the rest of the region. An analysis of fault plane solutions within the Coso data set show primarily extensional mechanisms with random orientations in the clustered earthquakes, and predominantly strike-slip mechanisms in other areas. There does not appear to be seismicity associated with continuous faults in the dome field nor those demonstrated to contain geothermal fluids.

THE GEOTHERMAL RESERVOIR

The geothermal reservoir concept presented here assumes the following; 1) in the near surface, the geothermal fluids migrate upward in or around the feeder dikes to the rhyolite domes and interconnecting structures, 2) the permeability is low near the surface and pressure is allowed to build within these features and, 3) the clustering of microseismicity is caused by the combination of existing tectonic stress and overpressure stress within the wall rock and feeder dikes. The clusters of hypocenters identified in the cross sections project to the surface in close association with rhyolite domes, however, a few clusters are located only in the proximity of mapped domes. The variation in location of the clusters, relative to the domes, is not surprising as the dikes would not be expected to be entirely vertical.

Field evidence suggests that the emplacement of the rhyolite domes began with a surface explosion as the magma came in contact with ground water and then degassed when confining pressures were released. It is likely that the granitoid wall rocks were severely fractured by the explosion and by the intrusion of the magma. When the magma began to cool in the feeder dike, the temperature differential caused the solidified magma in the feeder dike to autobrecciate (evidence of autobrecciation was found in at least one geothermal well). The venting of steam and other gas occurs steadily through the development of the domes. Eventually, in the near surface, the fractures are filled with precipitates and the gases are impeded from escaping from the vents, unless other factors prevail (such as Holocene faulting). The lower portions of the feeder dikes may remain open where the temperatures are higher and minerals are still in solution. However, it is probable that because of the tendency for the volcanic materials to alter to clays more readily than that of the surrounding granitoid rocks, over a period of time the fractured rim around the feeder dikes may be more permeable than the dikes themselves. If the dikes are permeable and intersect the main geothermal reservoir at depth, then significant pressures should be contained within them.

The observed microseismicity located near the rhyolite domes could be caused by slip on multiple short fractures in and around the dikes. The causative stresses would be from a combination of the existing extensional stresses and overpressurization in the dikes. Geothermal production should increase near to but not necessarily directly within the feeder dikes of the rhyolite domes. Although not demonstrated on the surface, there should be vertically dipping radial faults connecting the closely spaced dikes at depth. If the Coso Range underwent doming during the inflation of the primary magma chamber, horizontal faults could be formed as the basement rocks responded. This would create stresses similar to those that form flexural-slip faults found in anticlines. At depth, the radial faults, horizontal faults, and feeder dikes should all be reasonably well connected and generally permeable.

Based on the above assumptions and observations, the key geothermal targets are sites near rhyolite domes where highly fractured wall rocks rim the feeder dikes, especially those domes that have associated fumarolic activity (the fumaroles would suggest that there is still some permeability), and between the domes where interconnecting vertical faults intersect horizontal faults. Because the buried vertical faults are difficult to locate, the latter may not be

easy to target. The horizontal faults should be found to deepen to the north and south of the central dome field. The Coso geothermal reservoir, located within the upper few kilometers of crust, may be causing the observed patterns of microseismicity in the rhyolite dome field.

POTENTIAL GEOTHERMAL AREAS IN THE REGION

Indian Wells Valley is located south of the Coso Range where intense seismicity and tectonic deformation has been recorded. In 1982 a M 5.0 earthquake occurred that was preceded by nearly two years of foreshocks. The epicentral area is accompanied by continued vertical deformation and aftershocks from that event are still being recorded. Seismic tomographic mapping of the area shows at least two anomalies that occur at about 3.0 km depth and could be related to a magma body (Sanders, 1984; Walk, 1987). The seismicity data contained within the 1982 M 5.0 event has similarities with the Coso data set. In Indian Wells Valley, the primary distribution of seismicity appears to occur along a vertical fault, however, there are indications of at least two cylindrical shaped clusters as well. Other geophysical and tectonic data in this area suggests that geothermal resources may be present.

Due west of the Coso Range, in the Sierra Nevada, is Golden Trout Creek lava flow that is presumed to be 5,000 to 10,000 years in age and lying on a lineation of high levels of seismicity (Jones and Dollar, 1986). This belt of seismicity was one of the most seismically active features in southern California in 1984. Jones and Dollar (1986) suggested that this swarm could be related to the movement of magma, however, they did not find conclusive evidence to support that idea. The combination of young volcanism and high levels of seismicity suggest that a geothermal resource may exist. The microseismicity patterns should be investigated in more detail with the objective of identifying a new geothermal resource.

DISCUSSION

This paper provides an interpretation the Coso geothermal reservoir characteristics based on the observed seismicity patterns and, as such, does not benefit from the extensive drilling data available to geothermal developers. The data are derived from published geological and seismological research on the Coso Range. Other models that attempt to explain this unique geothermal resource should consider the extensive seismologic data base, as the current seismicity data will constrain the neotectonic development of the Coso range and hence the mechanics of the geothermal reservoir. Existing and yet to be obtained geothermal exploration data will test this concept. If the concept proves productive in identifying geothermal targets in the Coso Range, it could be tested in the Indian Wells Valley and the Golden Trout Creek localities.

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Chapter 7

ENVIRONMENTAL ISSUES AND RECLAMATION

ENVIRONMENTAL COMPLIANCE AT THE COLOSSEUM MINE

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Introduction

The Colosseum Mine is located on the northern slope of Clark Mountain in eastern San Bernardino County, California, approximately 50 air miles southwest of Las Vegas, Nevada. Surface access is obtained by leaving Interstate 15 at the Yates Well Road exit and driving 10 miles northwest on the old Colosseum Gorge Road.

Prospectors discovered silver in the Clark Mountain vicinity in the late 1860s and the Clark Mountain Mining District was organized in 1869 (Casebier, 1988). Active silver mining took place during the 1870s, followed by intermittent production of gold, copper, lead, tungsten, and fluorite from mines in the district from 1870 to the middle 1900s (McClure, 1988). Gold mineralization was discovered at the Colosseum during the early mining phase but no recorded production occurred until the 1930s. Small scale underground mining activity during that decade treated only about 3,000 tons of ore. The mine was closed in 1942 as a non-essential industry during World War II.

Intermittent exploration drilling took place during the 1970s and early 1980s. In 1986, the property was acquired by Dallhold Resources Inc., now part of the multi-national mining company, Bond International Gold Inc. Construction began in late 1986. The mill was placed into production in January 1988, and currently is producing at a rate of approximately 70,000 ounces of gold and 30,000 ounces of silver per year.

The mining property is located within the boundaries of the East Mojave National Scenic Area, which is designated as an Area of Critical Environmental Concern. Wilderness Study Areas border the property on the north and west sides.

Facility Description

The current operations at the Colosseum Mine include two open pit mines, a carbon-in-pulp (CIP) processing plant, and a tailings disposal facility. Initial ore reserves were estimated to be 10.5 million tons of ore with an average grade of 0.062 ounces of gold per ton. The average stripping ratio (waste:ore) is 4.0 to 1. The active mine life is estimated to be 9 years.

The current mining rate is approximately 26,000 tons of rock per day. This is accomplished through conventional surface mining techniques. Blasthole drills produce 6 1/2" diameter holes on a 15' x 15' square pattern. Ammonium nitrate based explosives are used to loosen the rock. Large (13 cu. yd.) front-end loaders mine benches that are 20 feet high. The haulage trucks are 85 ton capacity diesel-electrics. They carry the waste rock to its disposal site and the ore to the crusher to begin processing. The waste rock disposal site is classified as a Group "C" waste (California Regional Water Quality Control Board, Lahontan Region, 1987).

The processing plant is designed to treat 3,400 tons of ore per day, or 1.2 million tons per year. The process begins when the ore is dumped into a 48" x 60" jaw crusher which breaks it to less than 6" in size. This rock is fed into a semi-autogenous grinding (SAG) mill which, with the aid of 5" steel balls, breaks the rock into pieces smaller than 1/2". The ore is then pulverized in a ball mill with the aid of 3" steel balls. The ore is carried in a slurry from the SAG mill through the rest of the circuit.

After adjusting the density of the slurry, sodium cyanide is added to dissolve the gold from the rock. In a subsequent step, granules of activated carbon are introduced into the

slurry. The carbon adsorbs the gold cyanide complex onto its surface. The carbon is then screened out of the slurry and taken to another part of the circuit where the gold is removed from it. The carbon is then reactivated in a vertical kiln and reused.

After the gold has been extracted from the slurry, the slurry is a waste stream called tailings. The final step at the Colosseum Mine is to treat the tailings with sulfur dioxide to destroy any remaining cyanide. The tailings are then placed in a permanent disposal facility. After the solids settle out, the water is recycled to the plant. The tailings are classified as a Group "B" waste (California Regional Water Quality Control Board, Lahontan Region, 1987). Although 4,000 acres of land are controlled by the mine, less than 500 acres will be disturbed as a result of the mining and processing activities. The following table describes the different areas.

Facility	Planned Disturbance (acres)
Open Pit Mines	54
Mill/Offices	30
Stockpiles	25
Waste Rock Disposal	117
Haulroads	20
Tailings Disposal	203
	449

There are approximately 110 employees on site for normal production needs. During construction the manpower level peaked at 300. Two people, the Environmental/Safety Coordinator and the General Manager, deal with environmental matters as a normal part of their jobs. The Environmental/Safety Coordinator spends 80% of her time on environmental topics. The General Manager spends 25% of his time on matters relating to permitting and the environment.

Environmental Overview

There are two distinct habitat zones disturbed by the Colosseum Mine. The mine, mill, and tailings facility are located on a ridge on the north slope of Clark Mountain. The elevation ranges from 5,200 to 6,000 feet above sea level. The primary concerns for these areas were:

1. Disruption of bighorn sheep habitat and migration routes.
2. Disruption of prehistoric and historic archaeological sites.
3. Water quality impairment.
4. Air quality impairment.

The second area of concern was the utility corridor which contains the access road, the water supply, the water pipeline, and the power line which feeds the mine site. The elevation ranges from 2,600 to 4,100 feet above sea level. The primary concerns for these areas were:

1. Disruption of desert tortoise habitat.
2. A decrease in the desert tortoise population due to increased human contact.
3. Air quality impairment.
4. Raptor protection along the power line.

Utility Corridor

The utility corridor begins at the Yates Well Road exit off I-15, heads northwesterly to the original site of Ivanpah, then swings up the ridge to the east of the Colosseum Gorge. It follows the original road from the freeway to the Ivanpah townsite. The original road then

continues in the bottom of the Colosseum Gorge. This route was abandoned in favor of a new road constructed on the ridge to the east of the Gorge.

The access road is a graded dirt road 20 feet wide. Colosseum has two wells one mile north of the freeway which supply all the water to the site. On the desert floor, the pipeline lies adjacent to the access road. In the new section of road, the pipeline is buried in the shoulder. The powerline is also adjacent to the roadway in the same right-of-way as the waterline.

The major mitigation measures for the utility corridor are listed below, as described in various permit documents:

1. Prior to construction, the affected areas will be surveyed by a qualified biologist to locate and mark any tortoise burrows. The burrows will be avoided during construction. A tortoise awareness program will be conducted by the biologist to familiarize construction crews with the necessity of preserving tortoises.

2. During construction the road will be checked on a daily basis before start-up to relocate any tortoises. An employee who has been instructed in the proper handling procedures will conduct the sweeps.

3. During the operating life of the mine, the road will be checked for tortoises twice daily prior to shift changes.

4. A maximum speed of 25 mph will be mandated on the road for the life of the mine.

5. Speed limit and wildlife warning signs will be posted along the road.

6. To minimize disturbance to tortoise habitat, the right-of-way for the pipeline and power line will not be cleared or leveled.

7. The water pipeline will be installed above ground to avoid having to clear and level the surface. The pipeline will be placed on risers to allow for unrestricted movement of the tortoises. If the clearance is less than 8" for a linear distance of more than 20 feet, hand shovel excavations to a depth of 8" for a distance of 3 feet will be required.

8. Colosseum will fund a study to gather baseline data on the impacts of the utility corridor on tortoise populations.

9. All above ground facilities will be painted to blend in with the natural surroundings as much as possible.

10. The road cuts visible from I-15 will be treated with "Eonite" to reduce their visibility.

11. Protective measures will be incorporated into the design of the powerline to prevent electrocution of raptors.

12. Roads will be managed to reduce dust.

All mitigation measures were followed during construction and were continued into operations. It should be noted that all Colosseum employees are instructed in the correct procedures for handling desert tortoises even though that is not required by the permits. The company offers busing to the employees to reduce impacts along the road.

In a separate agreement with the Desert Tortoise Council, 30 acres of desert suitable as tortoise habitat, have been purchased by Colosseum and set aside for that purpose. This was to mitigate the loss of 10 acres of habitat caused by access road improvements.

Colosseum Gorge

Since the new road bypasses the Colosseum Gorge, plans were made by the BLM to enhance the development of riparian habitat in the Gorge. To this end, several mitigation measures were implemented as described in the permitting documents, they are:

1. The Gorge road will be blocked at both ends.

2. At the point of closure, shrubs will be planted to provide screening and aid in reclamation.

3. Colosseum will provide nursery stock (cottonwoods, willows, etc.) as directed by BLM in an amount not to exceed $1,000. Gap fencing to restrict livestock access to the Gorge will be provided as required by BLM.

Fifty Fremont Cottonwood trees were planted in the Gorge during the spring of 1988. Extensive damage, primarily trampling, has been caused by cattle. Planning is underway to design and install necessary gap fencing to protect the remaining trees. A second planting may also be required.

Mine. Mill, Tailings Facilities

The construction and operation of the mine, mill, and tailings facilities cause the biggest impact to the environment. The primary mitigation measures as described in the permitting documents were:

1. Buildings will be colored and sited to minimize visual impacts. All above ground facilities will be painted to blend in with the natural surroundings as closely as possible.

2. Develop a thorough, site-specific contingency plan and training program involving "worst-case" scenarios for accidents, hazardous materials release, or fire.

3. A historic and cultural resource salvage program shall be implemented in all areas that will be impacted by the project, and before such impact.

4. If needed, low visibility erosion control devices will be installed and their effectiveness monitored.

5. Frequent watering or chemical stabilization of operating surfaces, including ore stockpiles, will be implemented as a dust control measure.

6. Slopes of the pit areas, mine waste dumps, and the tailings impoundment will be routinely inspected for signs of instability.

7. Residual cyanide in the tailings will be detoxified before discharge to the tailings impoundment.

8. A comprehensive groundwater quality monitoring program will be carried out during the course of the project.

9. A double-lined seepage collection pond will be constructed downstream of the tailings impoundment to collect any seepage from the dam foundation and from underdrains constructed within the impoundment area.

10. The tailings impoundment will be constructed to contain all storm water including the PMF event. Adequate freeboard will remain to contain the effects of wind waves.

11. Spatial concentration of facilities will be implemented to minimize impact on wildlife and habitat.

12. An alternate source of water will be provided for the holder of the grazing lease.

13. Up to $3,500 will be provided for the construction of a wildlife guzzler.

14. Colosseum will pay for 8 hours/year helicopter time for 5 years to enhance studies of the local bighorn sheep population.

15. Analysis of small mammal tissue and bone for lead contamination will be made at the end of the first and second years of operation. Implementation of appropriate measures to reduce dust levels will be required if contamination is found to be significant.

After the initial survey, three prehistoric sites located within the tailings disposal area were excavated by an archaeological team from the University of Nevada, Las Vegas. This was done concurrently with mill construction during the summer of 1987. Twelve separate air-quality permits have been obtained from San Bernardino County to allow operation of the plant.

Any potential groundwater resource in the area was required to be protected from contamination by either lining the tailings disposal facility or by destructing the residual cyanide in the tailings. It was decided to destruct the cyanide with the Inco process which uses sulfur dioxide as the primary reagent. This system costs approximately $1.15/ton to operate. The cyanide levels stipulated by permit are less than 0.5 ppm Weak Acid Dissociable Cyanide (liquid fraction), 1.0 ppm total cyanide (liquid fraction), and 18 ppm total cyanide in the solid fraction.

The groundwater monitoring program measures 9 different wells around the tailings facility and in the Gorge. The wells were sampled monthly for the first 12 months of operation to establish a baseline. Sampling frequency is now every 3 months.

The Colosseum Gorge road has been a public access for over one hundred years. Since the present operations straddle the old road, a new public bypass was built which diverts the public away from the mine operations. The operations are visible from the new road and a display which describes the past, present, and future of the mine site is under development. A fence was constructed around the tailings site to keep cattle and visitors out. The plant site is also fenced for security purposes.

Reclamation

A mining operation cannot be permitted and built unless an approved reclamation plan is developed and adequately funded. The essentials of the Colosseum reclamation plan are as follows:

1. Topsoil will be salvaged whenever possible and stockpiled for future reclamation uses.

2. All escarpments created by mine excavation, fill, and the tops of all waste rock dumps will be modified to conform to the natural landscape to the maximum extent feasible. That is, rectilinear and flat mesa-like appearances will be avoided where possible.

3. All buildings and equipment will be removed from the site or covered with waste rock and/or topsoil at the conclusion of mine operations.

4. Pipeline, maintenance road, and access road corridors will be regraded to natural contours to the extent practicable.

5. Pits will be fenced and posted with warning signs.

6. The top of the tailings impoundment will be graded to direct surface runoff and prevent long-term ponding. The tailings will be covered with waste rock (contoured to conform to the extent possible to surrounding topography), stockpiled topsoil will be added, and the area revegetated with native species.

Topsoil stockpiling has been underway since the beginning of construction. As waste dumps are finished they will be reclaimed on an ongoing basis. Testing will soon begin for suitable plant species and revegetation techniques. A detailed closure plan will be developed during 1989, even though it won't be executed until the mid 1990's.

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CYANIDE IN THE ENVIRONMENT [1]

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In the right amount, cyanide can be toxic. As is the case with salt, aspirin, vitamins and other substances which can also be toxic, it is the level of administration that determines its toxicity, not its innate nature.

In water cyanide forms an equilibrium between two free cyanide species: ionized cyanide (CN-) and molecular, highly volatile HCN gas (DuPont,1984). The formation of HCN varies with pH, cyanide concentration and temperature. At a pH of 7 or less, nearly all of the cyanide is in the HCN form (fig. 1). Unless otherwise noted herein, the species noted as free cyanide is the ionic (CN-) form.

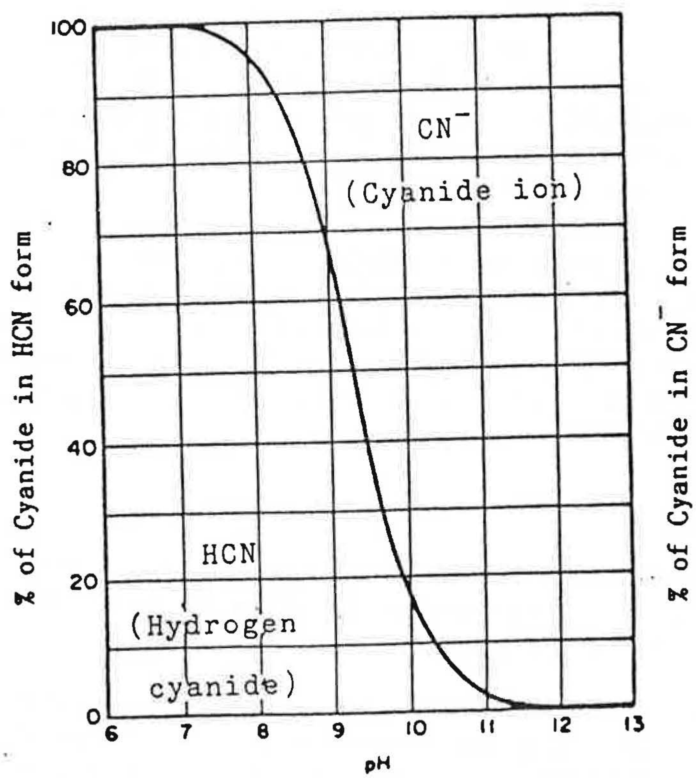

Figure 1. The effect of pH on the disassociation of HCN (DuPont, 1984).

1 Excerpts from the forthcoming book of same title;

We live in an environment sprinkled with cyanide. Fortunately, most of the cyanide we come in contact with is normally found in small amounts. When taken into the body by either ingestion or inhalation, cyanide is rapidly picked up by the blood and transported to the liver. Within the liver cyanide is converted to thiocyanate (SCN), which is then excreted through the kidneys into the urine (Freydberg, 1983).

Rats, however, although widely used for testing toxic substances, are not reliable indicators when it comes to cyanide (HCN). The average fatal dose for a 165 pound human is 52-260 mg/kg. Rats fed for over two years with food containing 100-300 mg/kg showed no signs of cyanide toxicity, hematological or pathalogical evidence of adverse effects (McKee, 1963).

Cyanide does not bio-accumulate in the food chain and is not mutagenic, teratogenic or carcinogenic. The present drinking water standard of 0.2 mg/L incorporates a safety factor of 21 times (Towill, 1978).

The very feature of cyanide which makes it useful to society, i.e., its chemical activity, works to remove it from the natural environment. The environmental affects on cyanide are so marked that free cyanide is considered a transient pollutant.

Urban Exposure

In urban settings, hospitals are the greatest producers of non-industrial cyanide wastes. These cyanide wastes are produced during lab tests performed for hemoglobin and uric acid determinations. In Buffalo, New York, one 930 bed hospital discharges 930 grams of cyanide per year. It has been estimated that the buffalo hospitals discharge over 5.6 kilograms of cyanide wastes to the environment each year (Ibid).

The major source of human exposure to cyanide occurs through the inhalation of cigarette smoke. Cyanide levels up to 1600 ppm have been measured in cigarette smoke (U.S. Dept.HEW,1964). A second source of cyanide found in the urban environment is produced by automobile catalytic converters. The burning of plastics such as polyurethane also produces cyanide (Ibid). In the industry, cyanide detectors are often tested by employees who blow cigarette smoke into them.

Domestic Exposure

Within the home, potassium cyanide is used as an ingredient in silver polish. Cyanides are uncommon in U.S. water supplies but are present in the kitchen where they are found both on and in foods and in the cooking atmosphere.

Sodium ferrocyanide (which is found in mining wastes), is used in amounts ranging from 50 to 250 mg/L to prevent caking and clumping in salt. The FDA regulations set a maximum limit of 13 ppm of sodium ferrocyanide in table salt. Sodium ferrocyanide (also known as yellow prussiate of soda), is very effective in this use. Since salt is a common ingredient used in food processing, sodium ferrocyanide is found in bread, breakfast cereals, natural cheeses, meat and salad dressings. The average daily amount of this cyanide compound consumed by the American public has been estimated at 0.6 mg, well below the 1.5 mg level considered safe (Freydberg, 1983).

Due to the widespread presence of cyanide use in the food industry, the EPA has established permissible levels of cyanide residues on foods. These cyanide residues range from a high of 250 ppm on spices, through 75 ppm on grains, 50 ppm on citrus, and down to 25 ppm on dried beans, nuts and cocoa beans (Towill, 1978).

The cyanide radical is found in a variety of naturally occurring plant compounds such as: glucosides, lathrogenic compounds, indoleacetonitrile and cyanopyridine alkaloids. Glucosinolates hydrolyze to the less toxic thiocyanates and are found in the *Crucufera* family. Representatives of this family include such favorites as: the Burpee white radish, Champion radish, cabbages, kale, brussels sprouts, cauliflower, broccoli, kohlrabi, turnips, rutabaga, horseradish, Ethiopian rapeseed, Indian or brown mustard, black mustard, white mustard and charlock.

The greatest source of cyanide in the kitchen originates on the range while cooking. Many plants and foods contain naturally occurring cyanide and other substances, which, when hydrolyzed through the cooking process, release cyanide (HCN) into the atmosphere. Plants containing cyanogenic glucosides release cyanide during both preparation and cooking. These compounds are found in sorghum, lima beans, tapioca, cherries, almonds, macadamia nuts, bamboo shoots, corn and stone fruits (Ibid).

Exposure in Nature

Interestingly, cyanide and its formation/consumption is an active form in the chemical processes of life. There are at least 16 varieties of bacteria that produce cyanide (HCN) that are found in nature. One of these, *Pseudomonas aeruginosa* strain 9-D2, is found on humans. In the forests *Marasmius oreades* found on the white cedar.

There are ovèr 30 fungi which also produce cyanide (HCN). What is commonly called .snow mold' on alfalfa and other forage plants is produced by an unidentified *psychrophilic oreades* which also produces cyanide.

Free cyanide is not found in the higher plants. Many, however, contain cyanogenic glycosides which produce cyanide (HCN) when hydrolyzed. These compounds have been identified in over 1,000 plant species comprising 90 families and 250 genera, e.#.; 150 species of *Rosaceae*, 100 species of *Gramineae*, 50 species of both *Aracea* and *compositae*. Although some plants contain cyanopyridine alkaloids which contain the cyanide group, they do not release cyanide.

It is believed that the sorghum plant is root disease-free because of the release of cyanide (HCN) from its roots. This release has been measured at 0.005 to 0.02 mg/24 hours per plant. Sudan grass reaches a maximum cyanide content of 2500 ppm in only seven days after sprouting from the soil. The cyanide content decreases as the plant matures and in 15 weeks has declined to around 250 ppm.

Livestock deaths caused by cyanide poisoning are attributed to the common vetch, lupine, grain sorghum and both Sudan and Johnson grass.

At least one insect, that commonly known as the millipede, of the order polydesmida secretes cyanide (HCN) as a defense mechanism (Ibid).

Due to the integration of cyanide in biological processes it should not be surprising to find it in plants. The levels of course would be expected to vary depending on what part cyanide plays in the plants metabolism. The California juniper (Juniperus californica) contains 5.8 mg/kg. The ubiquitous Joshua tree (Yucca brevifolia) 14.5 mg/kg and the Mojave Yucca (yucca

schidigera) 9.9 mg/kg. Shrubs also have cyanide lurking within them: Bladder sage (Salazaria mexicana) 17.9 mg/kg and the popular shrub from which a tea flavored drink is often made, Mormon tea (Ephedra nevadensis) 12.1 mg/kg (Ely, 1989).

Even desert soils contain measurable amounts of cyanide: 0.1 ppm (Ely, 1988,1989).

Industrial Exposure

Until recently, the greatest consumer of cyanides was the chemical industry where it is used in the production of fibers, plastics, and as a high temperature fuel, and in pharmaceuticals. With the increase of gold and silver prices in the early 1980's, the renewed interest resulted in the mining industry becoming the major cyanide consumer.

The electroplating industry is considered to be the greatest source of wastes containing high levels of cyanides. The liquid wastes that are normally created by electroplating for example, contain 15% free cyanide and a 10% mixture of ferrocyanide and ferricyanide plus traces of nickel and zinc. The waste slurry generally contains approximately 20% sodium ferrocyanide, 2% zinc, insoluble material and about 50% water (Towill, 1978).

Mining Exposure

Of late there has been considerable interest in gold and silver mines and their use of cyanide and its effects on the environment. Contrary to a popular misconception, cyanide has been used by the mining industry for nearly a century. Many examples cited as abuses are unfortunately steeped in ignorance of cyanide's properties and use. Although often sincere and misinformed, emotional issues generally are the motivation force to their objections. Literally millions of pounds of cyanide has been used successfully throughout the world during the last century without catastrophic consequences. In South Africa for example, people have lived on cyanided tailings.

Cyanide was first used in mining in the last century when it was discovered that weak solutions could dissolve both gold and silver. Being especially good in treating low-grade ores (less than 0.1 ounces of gold per ton), cyanidation is the method of choice. It has a long and successful history of use and an enviable safety record in industry. In nearly a century of use as a routine industrial process, record searches have found no known proveable accidental fatalities from its application.
(There have however, been suicides and lab accidents due to carelessness.)

As noted earlier, the majority species of free cyanide (CN^- & HCN) is determined by pH. At a pH of 7 or less, nearly all of the cyanide is in the HCN form. The pH therefore must be kept high in order to avoid toxic HCN fumes and to maximize the workhorse ionic form (CN^-), typically a pH of 11+ is maintained, about that of ammonia (ref. Table 1). This high pH is attained through the use of lime (CaCO) or caustic soda (NaOH).

Table 1. The pH of common substances.

0	battery acid	7	neutral,distilled water
1.7	toilet bowl cleaner (acid)	8	baking soda
2	lemon juice	9	borax
3	vinegar,carbonated beverages	10	detergent wash water
4	orange juice	11	ammonia
4-4.5	average acid rain	13	bleach
5	boric acid	14	household lye (NaOH)
5.6	normal rain		

(A.P.,1987, McKee,1963)

In the recovery of gold and silver from ores, a working solution is made from sodium cyanide (NaCN). The solution strength is commonly about 0.05% (500 ppm). The working strength solution sometimes is near 0.1% due to what is known as cyanicides in the ore itself, most notably copper minerals and ferrous sulphate. When applied to the ore the strength rapidly decreases as complexing with other metals occurs. The free cyanide concentration is further reduced as the removal of gold and silver from the ore proceeds. Environmental factors further reduce the cyanide levels. A tenfold reduction in free cyanide levels (500 ppm to 50 ppm) can occur (Ely, 1985).

Since the cyanide solution contains the precious metals, it is circulated through closed systems that are monitored to detect a leak if it should occur. A loss of solution is a loss of gold (and money).

When the process has reached the point of diminishing returns for any given amount of ore, the ore is washed with water until no free cyanide is detected. This washing process can generally remove the free cyanide from a heap within 30 days. This has been the method used since the introduction of the cyanide process nearly a century ago when, after the tails were washed they were disposed of onto land. If an acceleration of the neutralization process is desired, sodium or calcium hypochlorite (common bleach), is circulated through the system.

Environmental Cyanide Degradation

The cyanide ion (CN-) is useful because of its very high level of chemical activity. This very activity when exposed to the environment leads to its neutralization through degradation. In 1979 it was recognized that natural environmental processes play a major role in the degradation of cyanide. Important Canadian studies identified seven basic mechanisms which operate to destroy free cyanide: photodecomposition by sunlight, acidification by C02 in air, oxidation of 02 in air, dilution, complexation, adsorption on solids and biological action. These natural degradation mechanisms were found to reduce the cyanide content by 99.9% (Schmidt, 1981).

Perhaps the most important mechanisms are those that produce volatilization. Sunlight, acidification by C02 and oxidation by 02 result in the release of HCN to the atmosphere. Being highly volatile and lighter than air, the small amounts of HCN produced by mining processes are quickly dissipated and diluted by the atmosphere where it is destroyed. Given the low concentrations of cyanide used in mining, the potential amounts of HCN are also low. In recent tests over pregnant ponds, cyanide detectors had to be almost in contact with the surface of the water in order to detect anything (DeVries, 1985).

The complexation of cyanide with metals is a potent destruction technique. The insoluble compounds that result when iron is present (the rule rather than the exception with most ores), are ferricyanide and ferrocyanide. When exposed to sunlight, the insoluble ferricyanide is rapidly decomposed by the ultraviolet light. C02 and N2 are released during this decomposition along with small amounts of HCN which is quickly lost to the atmosphere. During a Canadian summer the half-life of this process is 20 minutes and in the cooler fall, 50 minutes (Schmidt, 1981).

The adsorption of cyanide on solids and the effects of biological action are often combined. The percolation of cyanide solutions through soil columns has been shown to remove 90-95% of the cyanide. Some bacteria, fungi and algae consume cyanide. Many, if not all, plants have the ability to metabolize cyanide (Towill, 1978).

In the cyanide destruction process, bacteria produce C02, NH3 and N2. In situations where cyanide discharges occur, bacteria concentrations have been noted. Some bacteria have

been found capable of living in KCN saturated solutions. In an anaerobic environment N_2 is the major gas produced whereas in an aerobic environment the cyanide is converted by bacteria to nitrate (Ibid).

Cyanide Exposure Risk

Cyanide is widespread in the environment and is inhaled and ingested regularly every day. We are exposed to both species of free cyanide from cigarette smoke, automobile exhaust fumes, on and in our foods, in our kitchens and in the work-place. Plants metabolize cyanide and bacteria feed on it, some release it, even while on our persons. When our systems are exposed to environmental cyanides, the liver readily converts cyanides to the far less toxic thiocyanate which is safely excreted through the kidneys.

Although cyanides are ubiquitous, cyanide levels in the environment are low enough that they are easily handled by most life forms - with the exception of hungry cattle. There is no evidence of cyanide biomagnification within the food chain. Toxic levels cannot therefore be attained. This is because low doses are rapidly detoxified by most species and large doses result in death. Cyanide cannot be considered a persistent pollutant. The environment is a threat to the presence of cyanide, not vice versa. Strange as it may seem, cyanide is a part of life.

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NATURAL REVEGETATION ON MINED LANDS

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The reclamation of mined lands is a process that is different for each site. The environmental setting around each mine is unique. The reclamation planned for the site has to consider the major environmental factors present, the type of mining to be conducted and the end use of the property. With these things in mind the goal of reclamation can be established and a plan designed.

Among the more important environmental factors to be considered are: topography, vegetation and wildlife, climate and especially precipitation. Water is the most important factor in reclamation: there is either too much or too little. In the one case protection against its erosional aspects is required and in the other its lack hampers some forms of revegetation.

The sites to be discussed herein are located in the Mojave Desert, an arid environment. The sites have been visited a number of times over the last decade to monitor what was occurring. Due to the circumstances associated with each site natural revegetation was the method of choice. The borrow pit is expected to produce in the future since the resource was not exhausted and the open pit mine was having difficulties that were challenging its survival.

Reclamation Philosophy

The reclamation of mined lands is a controversial topic. Some people when discussing reclamation are actually talking about restoration. Much like beauty, it seems that the goal of reclamation is also in the eye of the beholder. As a result, the judgement of whether or not proposed reclamation of a mine site is appropriate becomes a very subjective decision of the parties involved. This judgment is based on experience, personal goals and background, economics and the realities of life. These factors all color the decision process. This then leads to disagreements between mine operators, the regulatory agencies and outside interests. The outside interests may, or may not be directly affected by the project but are allowed into the process. The end result is often a negotiated settlement rather than a reasonable solution with a good potential for success. What is on paper does not always resemble what ultimately appears on the ground.

What is Reclamation?

At this point it is helpful to look at what definitions are applied to the reclamation of mined lands. We can use these to mirror the reclamation of the reclaimed lands being reviewed.

In California, reclamation is defined as:

"Reclamation" means the combined process of land treatment that minimizes water degradation, air pollution,damage to aquatic or wildlife habitat, flooding,erosion,and other adverse effects from from surface mining operations,including adverse surface effects incidental to underground mines, so that mined lands are reclaimed to a usable condition which is readily adaptable for alternative land uses and create no danger to

public health or safety. The process may extend to affected lands surrounding mined lands, and may require backfilling ,grading, resoiling, revegetation, soil compaction, stabilization, or other measures." (SMARA,Art. 2, 2733,1976).

The Bureau of Land Management regulations define redlamation as:

"Reclamation" means taking such reasonable measures as will prevent unnecessary or undue degradation of the federal lands,including reshaping land disturbed by operations to an appropriate contour and, where necessary,revegetating disturbed areas so as to provide a diverse vegetative cover. Reclamation may not be required where the retention of a stable highwall or or other mine workings is needed to preserve evidence of mineralization." (43 CFR Part 3800, Subpart 3809.05,(j),January 1, 1981.)

Restoration on the other hand is returning the land, in its entirety, to the original condition. There is therefore little, if any flexibility in the implementation of restoration. This is the method of choice of preservationists.

These definitions are important because they have a direct bearing on the goal of reclamation and on what form it will take. The present trend is a mix: to reclaim the land and restore the land's vegetative resources. Logic tells us, and rightly so, that the native or indigenous plants should do quite well in the site's environment. This conclusion is good as far as it goes.

What is overlooked however, is that the topography and nature of the remaining surface will change. The original vegetation cover was on a substrate and position that no longer exists. The postmining surface lacks the texture and chemistry of the original. In addition, there may be erosional aspects of the final surface that would preclude the original plant community.

The biggest obstacle to a successful reclamation program is always impatience. Some regulatory agency personnel demand some evidence of reclamation be implemented on the ground soon. (Interpretation:It has to be done very soon!) Most mining companies are willing to work on the reclamation of the property but they see little evidence of recognition that the life and circumstances of their project is being taken into consideration.

In the western United States, properties to be mined, as part of their operation, conduct ongoing exploration programs. Initial exploration commonly delineates an ore body that can be mined, initiating cash flow, while exploration continues. Typically, mining projects rarely have enough time and/or money to completely evaluate the invisible subsurface of the property. A plan is developed that, to best of their knowledge presents minimal risk of surprise. It is not at all unusual however, for additional ore or some other condition to be discovered that necessitates a change in both operation and reclamation.

Due to the capital intensive nature of mining, delays result in considerable cost. Obtaining the necessary permits and approvals is time consuming and an increasingly difficult process. The company is faced with a dilemma. If they commit to a reclamation plan that becomes unworkable as a result of unforseen conditions, they may (and likely will) , be required to begin the permit/approval process again. This places the project at risk. As a result, efforts already expended on reclamation could be completely wasted, not to mention the potential for delay.

In areas where there is a history of reclamation, a reclamation plan can be developed with considerable ease and assurance of success. This is a common situation experienced in urban areas where aggregate operations have been conducted. Increasingly, however, more mining projects are being initiated in remote arid regions where each site posses unique characteristics and challenges.

Natural revegetation is therefore an attractive approach to reclamation that can have both short and long-term benefits. It can be low cost and ultimately be the most effective form of revegetation. Natural revegetation can work well but it does have one limitation that some people find untenable- it takes time. And with some there is a question as to whether or not it will work the first time.

Reclamation Goals

The first decision in mined land reclamation is that of what the end goal should be. This seems to be an easily answered question in light of the definitions cited earlier; but is it?

In the case of the wordy California declaration, reclamation boils down to two things: mitigation of adverse impacts associated with the project and preparation of the land for some subsequent use.

The Bureau of Land Management regulation reduces to: in some reasonable way prevent unnecessary or undue degradation of the lands.

To the uninformed this would seem easy enough.Three things complicate the establishment of a reclamation goal.

1. The nature of mining i.e. it is a surface disturbing activity, the configuration of which is determined by the topography and the three-dimensional shape of the ore body.

2. The inability to see below the surface to precisely and in detail determine both the physical and metallurgical nature of the subsurface.

3. What the actual life of the mine will be. The market and physical aspects of the deposit as revealed by actual mining of the deposit are only two of the factors that determine the mine's life.

Numerous questions arise that impinge on setting a concrete goal not subject to change. Should there be only a single goal? Should there be a short and/or long-term goal for reclamation? Without drilling a hole every ten feet, how do you discover all of the geologic structures and metallurgical changes within the deposit? How do you determine what the subsequent use of a property will be in ten years? Twenty years? One hundred years or more? What is reasonable? Will there be an adverse change in the market ? Will there be new uses for other minerals in the deposit? Ad infinitum. These and other questions must be answered. Reclamation must occur. All impact the goal for reclamation.

The following two examples illustrate how natural revegetation can assist in the resolution of the problem. The problems associated with natural revegetation and the level of its success is noted when mirrored against existing reclamation definitions.

Both projects were initiated on previously undisturbed lands. One project was a borrow site for highway construction materials; and the other is a small open pit mine. Both are located in arid lands within the Mojave Desert in southern California. Natural revegetation was an integral part of reclamation for the reasons described below.

WILDWASH BORROW SITE

The Wildwash borrow site is located about 15 miles north of Victorville. It is east of I-15 by the Wildwash off-ramp. The Wildwash borrow site is a 230 acre parcel located on lands owned by the Southern Pacific Land Company. The lands were leased by the E.L. Yaeger

Construction Company, Inc. It was proposed that 1,000,000 tons of aggregate would be recovered for use in resurfacing projects along I-15.

Located at the base of Wildwash Mountain, the borrow site sits on an alluvial fan of considerable extent. It is at an elevation of about 3000 feet. Temperatures range from near 0° F. to around 115° F. Precipitation is around four inches annually. No surface waters exist on the site and little braiding exists due to the high degree of permeability existing in the fan.

The site and surroundings is located in the Creosote scrub plant community. Typical representatives species are listed in table 1. Wildlife are typical of that found in the Mojave Desert, Black-tailed jackrabbits, coyotes, assorted birds and small reptiles.

Table 1. Vegetation

Creosote bush	*Larrea tridentata*
Barrel cactus	*Ferrocactus acanthodes*
Hedgehog cactus	*Echinocereus Englelmanni*
Beavertail cactus	*Opuntia basilaris*
Desert mallow	*Sphaercea ambigua*
Desest trumpet	*Eriogonum inflatum*
Cheesebush	*Hymenoclea salsoJa*
Mustard	*Brassics geniculata*
Tumbleweed	*Salsola kali*
Sandmat	*Euphorbia polycarpa*

Given the paucity of precipitation and semi-active state on the surface of an old alluvial fan, no soils in the common sense (A, B, & C horizons etc.) do not exist. The creosote bushes are small both in spread and height (3'-5' & 1.5'-4') as compared to others in the desert. The cacti are small and widely scattered. The gravelly soil is composed of granitic and metamorphic erosional products. The fan is made up of sand and gravel sized components with considerable cobbles and an occasional boulder up to six feet in diameter.

Conventional open pit techniques involving the use of bulldozers, front-end loaders, dump trucks and conveyor belt systems were used. Water was conveyed to the site from a well west of the site, near the Mojave River, by pipeline. Some crushing, screening and washing of materials was accomplished onsite. An asphalt batch plant was also installed on the property along with an electrical generator for power.

Since the projects demands were small when compared to the volume of the alluvial fan, mining to a depth of only 20 feet was proposed. This would prepare the site for use beyond the project at hand. Pit walls were graded to slopes of 2:1. A soilbank was formed from the meager supply that existed.

Since the project site contained considerably more volume than that needed for the project at hand, the site would at some time in the future be used again. There are no residential lands in the vicinity and the lands surrounding the site are vacant public lands for the.most part. No significant off-site impacts were therefore associated with the project. It was desired to make the aggregate resources readily available for future use since turnaround time is important to fulfilling Caltrans contracts in the desert. Natural revegetation was decided upon since there were little soil materials available.

Reclamation

When the site was completed (1980), the asphalt batch plant was removed. The ungraded pit sidewalls were graded to a 3:1 slope. The soilbank materials were scattered over the pit floor. The water pipeline was removed. All trash and debris was removed from the site. The site was graded, smoothing out the minimal stockpiles that remained. The unlined water supply pond berms were left in place for future use.

The site has been used for dry camping, ORV play, hunting and shooting since the cessation of borrow activities. Due to the west winds typical to the region, the pit floor has assumed a fresh desert pavement form. The side walls and pit face have experienced some ravelling but no runoff problem exists due to the permeability of the alluvial fan. There is some trash scattered around the site from post-operation visitors. There does not appear to be any domestic trash dumping occurring at the site. Almost any day the site is visited in good weather, someone will be around with an ORV, shooting or parking.

Natural revegetation is minimal. Mustard, sandmat, desert mallow, desert trumpet and cheesbush have returned to the site but they are scattered and provide sparse cover. Small unidentified annual grasses (3-6 inches high) provide near total coverage of the site. These same grasses grow on the surrounding lands. The grasses do not grow on the fines that remain in the washing area. Being annuals however, at times other than spring, the surface appears barren except upon close examination.

The site appears stable except for a little raveling on the sidewalls. The desert pavement-like surface provided by the gravel does not provide particulates for off-site transport by the wind. If disturbed by vehicles a dust source is created.

When compared with the reclamation definitions cited, the site is reclaimed. It is stable, impacts have been mitigated and it awaits another cycle of mining activity. No unnecessary or undue disturbance occurred although it could have been argued a smaller area could have been mined more intensely. If this had occurred the reclamation of the site would have been far different. Given the sporadic need for these materials, such use will in all probability occur in the distant future. Being adjacent to I-15, it is only a matter of time.

Natural revegetation has occurred on the site but its density when compared to the adjacent undisturbed lands is far less. This is due in part to the larger rock surface resulting from the gravel spread. (The gravel pieces are larger than the those on the original.) Grasses were the first species to invade the site. Due to the gravel mosaic substrate it will be some time until the site reaches the plant density it originally possessed.

RATTLE SNAKE MINE

The Rattle Snake Mine is located on public lands in the East Mojave desert, about five miles east and two miles south of the old site of Landers. It is on the northeast flank of the Von Trigger Hills. It is a small open pit gold mine discovered in 1972 by George Wright who named it.

The site is slightly above the floor of Lanfair Valley at an elevation of about 3700 feet. Annual temperatures range from near O° F. to over 120° F. Precipitation is around six inches pere year. Bedrock is within inches of the surface, there being little of what is normally considered to be soil.

The mine is within the Creosote scrub plant community. Typical species present are listed in table 2. Wildlife is also typical for the Mojave Desert. Coyotes, black-tailed jackrabbits, assorted birds and small reptiles and of course rattlesnakes. Desert tortoise have not been seen at the mine but have been sighted north of the site in Lanfair Valley.

The creosote bushes are mature and considerable plant diversity is seen. The cacti and all other vegetation appear healthy. The soil is composed at the mine site, primarily of erosional products derived from the diorite rock that rests only a few inches below the surface.

Table 2. Vegetation

Creosote bush	*Larrea tridentata*
Mojave yucca	*Yucca schidigera*
Great basin sage	*Artemisia tridentata*
Squaw tea	*Ephedra nevadensis*
Desert Rattleweed	*Astragalus crotalariae Davidsonii*
California buckwheat	*Eriogonum fasciculatum*
Goldenbush	*Haplopappus linearifolius*
Desert Mallow	*Sphaeralcea ambigua*
Cheesebush	*Hymenoclea salsola*
Desert Aster	*Machaeranthera tortifolia*
Sandmat	*Euphorbia polycarpa*
Barrel cactus	*Ferocactus acanthodes*
Hedgehog cactus	*Echinocereus Englemannii*
Silver cholla	*Opuntia echinocarpa*

This small mine uses a bulldozer to excavate the pit to provide an ore stockpile. The ore is then placed on a impermeable leach pad for heap leaching. Water is provided the site via a pipeline from a well about one-half mile north of the mine. A electrical generator provides electrical power. The project has been plagued by lawsuits and little production has occurred. As a result, long periods of time have transpired during which the mine was idle.

Reclamation

During the idle periods experienced by the mine, natural revegetation began encroaching upon the site. Grasses and annuals were quite successful in revegetating the site. What was more interesting however, was what was occurring at the pit.

The pit is approximately one-half acre in size and about 25 feet deep. Since the pit is worked by a bulldozer, one side (the east) has a shallow slope which leads to the floor of the pit.

Since the pit is in bedrock, any precipitation falling within its confines remains, it does not percolate into the ground. During the periods of idleness, precipitation created a small pond that filled the bottom of the pit to a depth of as much as five or six feet. Fractures in the bed-rock conducted water from above and around the pit into it through seeps. As a result the pit became an almost perennial source of water.

An interesting example of natural recovery processes then took shape. Taking advantage of this oasis, wildlife were attracted to the site. Riparian vegetation began to take hold around the edges of the pond and flourished. Animals began coming to the site regularly. A number of trails crisscrossed along the pit's side down to the water. One could sit on the side of the pit and watch quail trot down to the water and other birds fly in. Coyotes frequented the watering

hole with as many as seven being seen at one time. Footprints around the water's edge indicated that other nocturnal animals also were present. A unique ecological niche was inadvertently created.

Although the site has not seen the last of its mining activity, some natural reclamation has occurred. The periods of idleness have shown that an interesting and diverse ecological niche will establish itself and flourish, within an open pit mine, even in the hostile environment of the Mojave Desert. Given the open pit mines that are presently operating and are being planned in the East Mojave Desert, this type of ecological niche, beneficial to wildlife, will recur.

As a result, there will be a naturally occurring wildlife enhancement that will enrich the environment of the East Mojave Desert. As this type of mining continues in the future, and after the mines have been completed, it will become possible to observe a wide variety of wildlife in widely separated areas in a way that cannot be presently duplicated. Existing water sources are so small in extent that it is not easy to observe wildlife without disturbing them.

With some of these proposed pits being up to 40 acres in size, some interesting settings will develop. Wildlife densities will probably increase around these mines once operations have been completed. As has been seen at Cronese Dry lake within the last decade, even dry lakes can contain water for up to several years as a result of wet periods.

The site meets the criteria cited as reclaimed although the operation is a long way from being completed and the ultimate used that developed. was unforseen. There is a lesson to be learned in this in that natural reclamation processes are persistent an in some cases unpredictable. This particular case demonstrates the <u>resilience</u> of the desert environment. The appellation of fragility to the desert environment is misapplied and overdrawn as this example clearly demonstrates.

Unfortunately this site can no longer be studied. During recent general cleanup activities by the new operators, BLM staff suggested the pit be filled in. That is what the operators did.

Enhancing Natural Revegetation

From these two examples and others reviewed but not cited herein, some suggestions can be made that will enhance the natural revegetation process.

1. Remove or bury all trash.

2. The surface of the site should be smoothed out.

3. If available, place soil from a soil bank over the smoothed surface.

4. Harrow or rake the surface.

The revegetation of a site can be accelerated by artificially seeding the area. This can be difficult however, due to seed predation by birds, ants and some rodents. Three approaches to reseeding can be taken: seeding the site with annuals, seeding the sites with natives and seeding the sites with both. All seeding should be accomplished just before the winter rains or snows (watch out for hungry birds!). Alternately the seeding can be initiated at end of winter or at the beginning of spring.

Seeding with Annuals

Where erosional problems (sheetflow) may occur or for cosmetic reasons, the site, after preparation can be artificially reseeded. A seed mix used to accomplish this is composed of:

Rye grass	20#/acre	*Lolium multiflorum*
Barley	20#/acre	*Hordeum vulgare*
California poppy	5#/acre	*Eschscholiza californica*

Seeds for this mix are readily available. The seeds should be broadcast over the area and then either be raked into place or have a maximum of one-half inch of soil or fines placed over them. In an arid environment do not hydroseed.

One advantage of this mix is that, except for the poppy, unless fertilizer is added, the rye and barley will not persist, they will die off and not compete with the native plants (Van Kekerix, 1986). In the springtime germination can be enhanced by watering the site daily for about a week and then withdraw watering gradually over the following three weeks unless it rains. If snow is common at the site, it is better to let nature take its course in the spring, i.e. do not water the seedbed. Sprouting normally occurs within several days if it is warm enough.

Mitigation is provided for precipitation erosion damage in an arid environments by this mix, not to mention the greening effect. The remains of these annuals will provide humus and seeding sites for the encroachment of the native species which surround the site.

Seeding With Natives

Native seed mixes can be applied in the same way as annuals. If not raked into they can be blown away or become birdseed or ant fodder. They are more expensive and do not often exhibit the high germination rate of the suggested annuals. Unlike the annuals which need fertilizer to persist, natives will do quite well once they are established. For the best results the seeds should be collected locally rather than be purchased, They will be fresher and no doubt will attach to their propriety.

Annuals and Native Mixes

With the disturbed surface prepared as state earlier, native plants will encroach upon the site, reclaiming it naturally. This is a process that proceeds slowly. If the site is stable this process will ultimately revegetate the site. The plant density may be less depending on the type of substrate available. A fine gravel (-3/8") appears to work the best for this approach.

If there is a need to expedite revegetation of the site, a mix of the annuals and natives will combine the best of both worlds. They can be applied as above and their germination accelerated by sprinkling they in the manner described.

Natural revegetation is a process that proceeds regardless of what we do. Natural revegetation can be enhanced with little effort by preparing the surface. Revegetation of the site can be accelerated by reseeding the site with annuals, natives or a mixture of both. Germination can be encouraged by watering in the spring. The natural revegetation process is one that should have greater utilization and be more widely used. It works.

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WATER REDUCTION INNOVATION IN HEAP LEACHING

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In the heap leaching of precious metal ores, solutions containing very low levels of free cyanide are percolated through the ore. During the process, water is consumed by adsorption in the ore and evaporation where solutions are exposed to the atmosphere. Typical evaporation sources at a heap leach operation are: barren and pregnant solution ponds, open ditches and at the heap.

In an arid environment where temperatures are high and the humidity low, evaporation losses can be significant. At Victorville, California (which is located in the western Mojave Desert), evaporation has been measured at 83 inches per year (Hardt, 1971). At this rate, 51.7 gallons of water evaporate from every square foot of exposed water surface every year. Put another way, every acre of water exposed to the atmosphere loses 2,253,649 gallons (6.9 acre-feet*) of water to evaporation.

In a heap leach operation an ore particle must contact solution over its entire surface in order to maximize the extraction of precious metals. This requires the leaching solution to be applied in a manner that will maximize contact with ore particles during percolation through the heap. Until recently, spraying and ponding were the two methods of choice used to apply solution to a heap.

When the application of solution by sprinkling onto a heap is chosen, two methods are used: sprinkler heads or wobblers. Special sprinkler heads are placed across the top (and sometimes the sides) of a heap along with the piping needed to convey the solution. The solution exits the sprinkler in a spray with particles ranging in size from mist to raindrop. Drops up to 0.25" are produced by variable lengths of tubing which wobble under hydrostatic pressure. Sprinklers produce a neat geometric pattern of application whereas wobblers cover an irregular area in a random manner. When the drops strike the heap's surface they are further dispersed as they splatter and ricochet back into the air. In an arid environment both methods produce a best-case condition for evaporation by producing large surface area to air contact environment. In addition to the water loss, valuable cyanide is destroyed by exposure to the air and sunlight.

When ponding is used the heap must first be graded to make it level across the upper surface. The leveled surface is then divided into rectangular ponds by constructing a grid of berms. A piping network is then positioned for the introduction of solution to the ponds. Although an atmospheric spray is not produced, considerable water surface area can be exposed in a large heap leach operation. In both cases the replacement of water lost through evaporation has costs that can be measured in energy, time and money. The conservation of water is therefore an item of concern, especially in an arid environment.

A recent innovation in the application of solution to a heap is gaining considerable acceptance. The innovation involves the use of drip irrigation watering systems for heap leaching. Drip irrigation is the result of agricultural water conservation concerns arising out of droughts. Drip irrigation utilizes small emitters which produce water in amounts ranging from a fraction

* One acre-foot= 325,830 gallons (one foot deep over an acre).

of a gallon to several gallons per hour. (Fertilizers are commonly added to the water in agricultural applications.) The solutions are emitted at or beneath the surface. As a result, evaporation is nil. Being very efficient in conserving water, drip irrigation systems are very popular in arid regions throughout the world. In Israel for example, such systems are ubiquitous. Drip irrigation systems and the manuals for their installation and use are commonly available in hardware stores in southern California. At least one company makes special drip systems available to the mining industry. In 1986 such a drip irrigation system was installed at the Rochester Mine near Lovelock, Nevada and its effectiveness and cost was monitored (Dixon, 1987). The results of this study indicated competitive costs when compared with spray systems.

A number of heap leach operations in California and elsewhere have already converted to drip systems for the application of cyanide solution to heaps. Through the use of drip systems, evaporation losses have been cut by 80-90% at the Yellow Aster Mine near Randsburg and at the Morning Star Mine in the East Mojave Desert. At the Morning Star Mine this amounts to a minimum saving of about 6,000,000 gallons of water (18.4 acre-feet) per year. Other mines using the system have reduced evaporation losses upwards of 25%. Local environmental conditions affect the savings realized.

Drip systems being used in mining applications utilize lines of 0.5" tubing with emitters spaced along them at 32" intervals. The lines of emitters are placed parallel to each other and are separated by anywhere from 12" to 36". These emitter lines are connected to manifolds ranging in size from two to six inches in diameter. The number of emitters used varies depending on how the drip system is installed. Some operators choose to lay the emitter lines over the entire heap in one installation, while others move them around the heap on a predetermined leaching schedule. At the Morning Star Mine a drip irrigation unit covering 122,000 square feet (2.8 acres) uses 18,000 emitters placed on a 32" grid. This drip irrigation unit is moved from time to time around the heap as the heap is enlarged. Another operation in southern California has a drip irrigation unit covering 1,000,000 square feet (23 acres) which contains approximately 150,000 emitters. The lines in this unit are also moved around the heap.

The emitters used in heap leaching typically produce about 0.033 gpm (2 gph). Application rates vary depending on the character of the ore. Application rates can be varied by changing system pressures (typically operated around 16 psi) or emitter size.

One of the major assets of using a drip system is the better distribution of solution to the heap. The saturation cones beneath the emitters typically converge within six inches .of the surface (Dixon, ibid). At the Morning Star Mine the surface of the heap is dry except directly at the contact point between the emitter and the heap; the lines have to be lifted to actually see the contact point. Ponding rarely occurs on the surface with a drip system. The lack of puddles or ponding eliminates bird and other wildlife attraction potential.

The better saturation of the heap also reduces the long-term need for water. This additional water savings is a result of the uniform saturation that expedites the leaching to the point of diminishing returns. The other application methods do not give as thorough saturation. The bane of a heap leaching operation are the channels that develop within the heap and divert solution flow. Recovery of the precious metals begins at a higher rate as a result of saturation. At the Morning Star Mine recovery rates jumped significantly when the drip system was first installed. The solutions apparently reached materials not touched by the previous sprinkler system. After a time the recovery rate descended to an expected level. In short, the earlier recovery of metals through improved saturation reduces the time needed to reach the point of diminishing returns. This in turn reduces the amount of water and time necessary to leach the heap.

Drip systems are not however trouble-free. Scaling and orifice plugging occur as with spray systems. Unplugging a drip system does not pose the problem to personnel that spray systems present. Raincoats, boots and other gear are not require with the passive drip system. If an emitter cannot be unplugged it is easily replaced.

Scaling is primarily a problem associated with the low humidity and high ambient temperatures experienced in the summer. With leach systems operating around pH 12 they are ripe for scaling problems no matter what application system is being used. When the concentrations of carbonates and salts in solution exceed saturation points, precipitation occurs, typically around the emitters. As with any chemical process, close monitoring and maintenance is required. No one product for scale prevention or control seems to be preferred by operators.

In areas where low temperatures occur, freezing at the ends of emitter lines has been noted (Dixon, ibid). Warming temperatures thawed the lines without any apparent damage to the system. At the Rochester Mine the emitter lines were buried two to three feet below the surface to eliminate the problem, but this sacrificed these lines to the heap. In areas where the freeze line is not so deep, a shallow covering of ore could eliminate both freezing and permanent burial of the emitter lines.

Cost comparisons of the various application systems used are not in total agreement. Operators having experience with all of the systems mentioned above agree that costs are slightly higher in some instances for a drip system. By comparison however, the costs associated with the establishment and maintenance of a level surface for ponding seem to be greater than those of a drip system installation.

Drip systems provide better heap saturation than do spray or ponded solutions. This results in a more rapid recovery of precious metals and, in turn, reduces long-term water needs for the project. A significant reduction in water consumption is realized by the reduction of evaporation losses. These savings range from 25% to 90% with most reports being in the high range. The lack of puddles or ponding on the heap eliminates the potential attraction of birds and other wildlife. The reduction in water demand as a result of benefits associated with a drip system can produce time and energy savings from reduced pumping. The life of the project is also reduced due to more rapid and efficient recovery of the precious metals. Scaling and orifice plugging can occur depending on system chemistry. In some climates freezing can also develop into a problem. At the present time the application of cyanide solutions to a heap leach operation by drip irrigation methodology is the system of choice.

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CH-1064 REV. 12-88

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Sean

To		Initial	Date
1	SD		
	ASD		
	ADMIN		
	RES		
	OFER		
	PA		
2	Minerals		
	EEO		

Action by
Surname by
Return to

B

April 26, 1989

Mr. Ed Hastey
UNITED STATES DEPARTMENT OF THE INTERIOR
Bureau of Land Management
California State Office
2800 Cottage Way
Sacramento, CA 95825

Dear Ed:

Enclosed are charts outlining my presentation at the California Desert Mineral Symposium. I agree that the Symposium was extremely successful in reaching an informed, interested audience; presenting diverse information and perspectives; and perhaps most important, getting people talking together so solutions to problems could be worked out and timely decisions made. You and your group did an excellent job in organizing the Symposium and I was very impressed with the results.

I have made two previous presentations at your Arizona training center, and we welcome the opportunity to provide factual information about sodium cyanide so informed decisions can be made. You have my best wishes for shepherding the BLM mandate at a critical period to maintain the multi-use concept.

Sincerely,

Ron Geyer

H. Ronald Geyer
Technical Service Consultant

HRG/ldl

Enclosure

CYANIDE SAFETY

- DU PONT SAFETY
- USES
- HAZARDS/TOXICITY
- CYANIDE POISONING
- SHIPPING & USE SAFETY
- VIDEO - SIMULATED SPILL
- SODIUM CYANIDE FACTS

LOST WORKDAY CASES

NATIONAL SAFETY COUNCIL DATA
RATE: PER 200,000 WORK-HOURS

	1982 - 1986 AVERAGE
ALL INDUSTRY	2.11
CHEMICAL INDUSTRY	.54
DU PONT (CHEMICAL)	.027

DU PONT RATE:

78 TIMES BETTER THAN ALL INDUSTRY
20 TIMES BETTER THAN CHEMICAL INDUSTRY

DU PONT'S SAFETY APPROACH IS BASED ON:

- ALL ACCIDENTS CAN BE PREVENTED
- SAFETY IS A CONDITION OF EMPLOYMENT
- NO OTHER OPERATING OBJECTIVE (PRODUCTION, COST, QUALITY, ETC.) IS MORE IMPORTANT THAN SAFETY

INHERENT IN OUR SAFETY APPROACH

ARE "RIGHT-TO-KNOW" CONCEPTS FOR

- EMPLOYEE SAFETY
- PUBLIC SAFETY

CYANIDE USES

HYDROGEN CYANIDE (HCN): 1+ BILLION LBS/YEAR IN U.S.

- TEXTILE FIBERS (NYLON)
- METHACRYLATE RESINS (CLEAR PLASTIC GLASS)
- PHAMACEUTICALS
- INSECTICIDES/HERBICIDES
- SURFACTANTS/CHELATING AGENTS
- ANIMAL FOOD SUPPLIMENTS
- DYES (INDIGO)
- SODIUM CYANIDE AND OTHER METAL CYANIDES

SODIUM CYANIDE: 100 MILLION LBS/YEAR IN U.S.

- MINING (GOLD, SILVER, COPPER, MOLYBDENUM, LEAD, ZINC)
- ELECTROPLATING
- HEAT TREATING
- CHEMICAL
- JEWELRY

Considerable data has also been developed, and now in practice, showing the ability to reduce geomembrane thickness by using geotextiles. It is possible to obtain the same puncture resistance of a given geomembrane when you reduce it's thickness to half and add a 6-8 ounce geotextile. Typical results using geotextiles with geomembranes of different thicknesses are shown in the attached bar graph. The geotextile can offer other benefits besides lower cost and higher puncture. This can include a drainage medium and a clean surface to weld on.

Because of these developments and in some cases the hugh size of the leach pads under design it is imperative that the designer look at the alternatives. Depending upon site conditions, many alternatives can be very cost effective. Thus it is becoming more common in practice to consider material thickness, use of geotextiles, and geomembrane material in relation to the earthwork considerations.

In selecting a geomembrane and its design it is important to adapt the application needs and environment to the liner needs. Common cause of liner failure should be understood. These failures can include 1) cold temperature failure, 2) degradation due to high temperatures, 3) chemical attack, 4) biological attack, 5) wind damage, 6) physical damage such as puncture, 7) UV degradation, and 8) seam failure. The design and selection process should take into account the worst case senario for the above.

QUALITY

A good quality assurance program avoids future problems. With geomembranes it is important to include the material property specifications. This can include a certification of each roll delivered to site showing the results of physical tests against specifications. There should be an inspection for damage upon delivery and an inspection as the liner is deployed to insure no damage or the need for repair.

Probably the most critical area for concern is the field seaming. All seams should be inspected visually as well as using both non-destructive and destructive test methods. Included in non-destructive testing are air jet, impact testing, ultrasonic testing, and vacuum box testing. Destructive tests include tensile testing and peel testing. The non-destructive tests will only show if there is a leak or other area of concern. Destructive tests will show how strong the bond is. Because destructive tests require taking samples from the actual installation they are generally taken at intervals of 500-1000 feet. Any seaming operation should be fully tested prior to actual production seaming. Because field seaming takes place in an outdoor environment, all seaming conditions should be rechecked if there is a major change in conditions. Typical causes for rechecking would include a temperature change in excess of 25 degrees, a wind velocity change of more than 20 miles/hour, and a change in conditions such as seaming where the surface goes from dry to wet, etc.

Once a section is completed and tested efforts should be made to eliminate or reduce traffic in this area. Good record keeping is also an important part of quality. This should include accurate as-built drawings, retain samples of the material and seams, environmental conditions, etc.

CONCLUSIONS

Geomembranes have been used for environmental barriers in the mining industry for many years. In the past decade there have been many advances in the knowledge and use of geomembranes and because of a greater concern for protecting the groundwater there has been constant efforts made towards improving the geomembrane system. A lot of the developments in these systems for mining applications have been adaptations from experience gained with liner systems and designs with hazardous waste. As we continue to develop these systems and improve them it is important to the designer to have data. This paper has been an attempt to briefly review the use of geomembranes in the mining industry at present.

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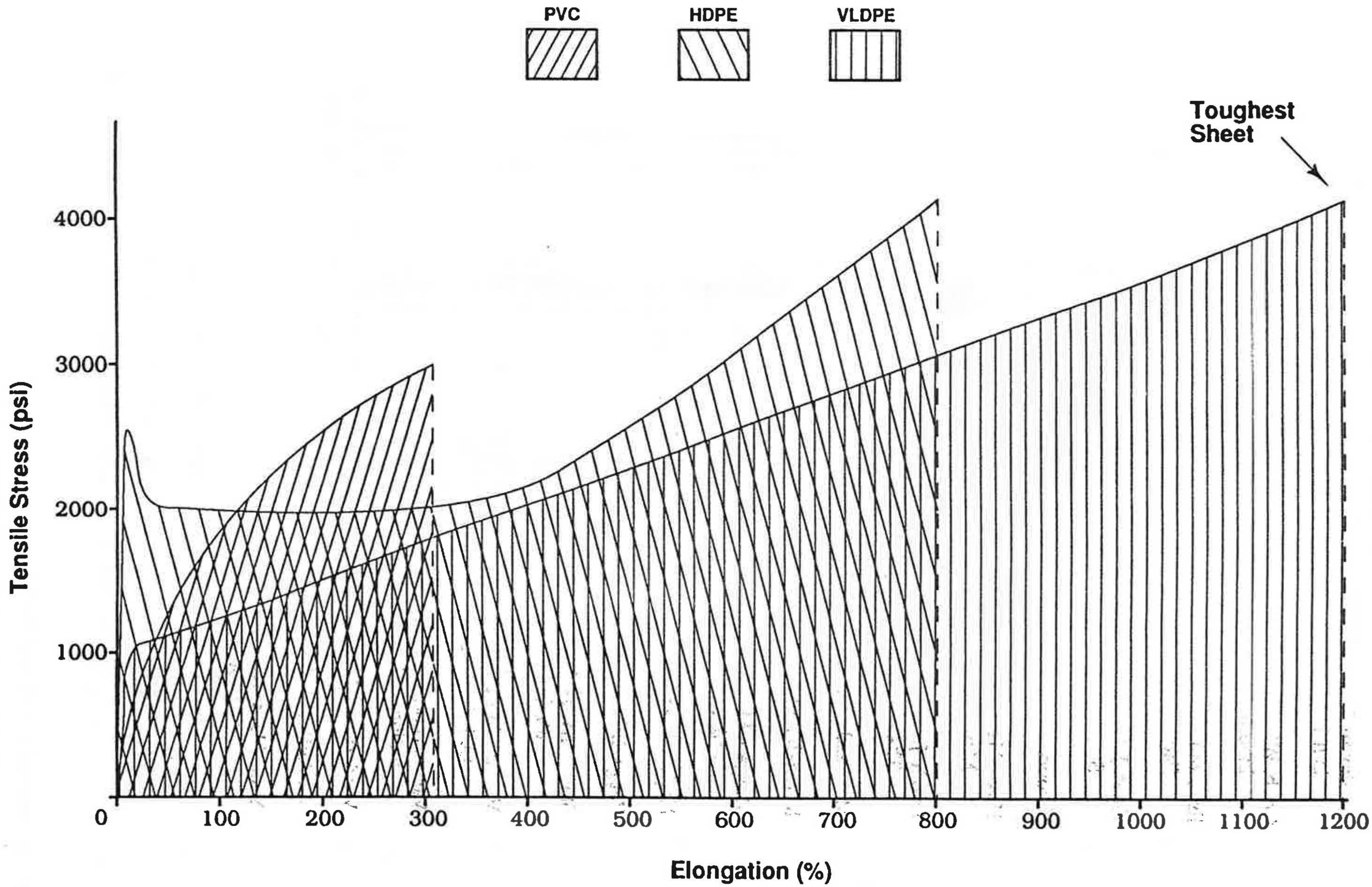
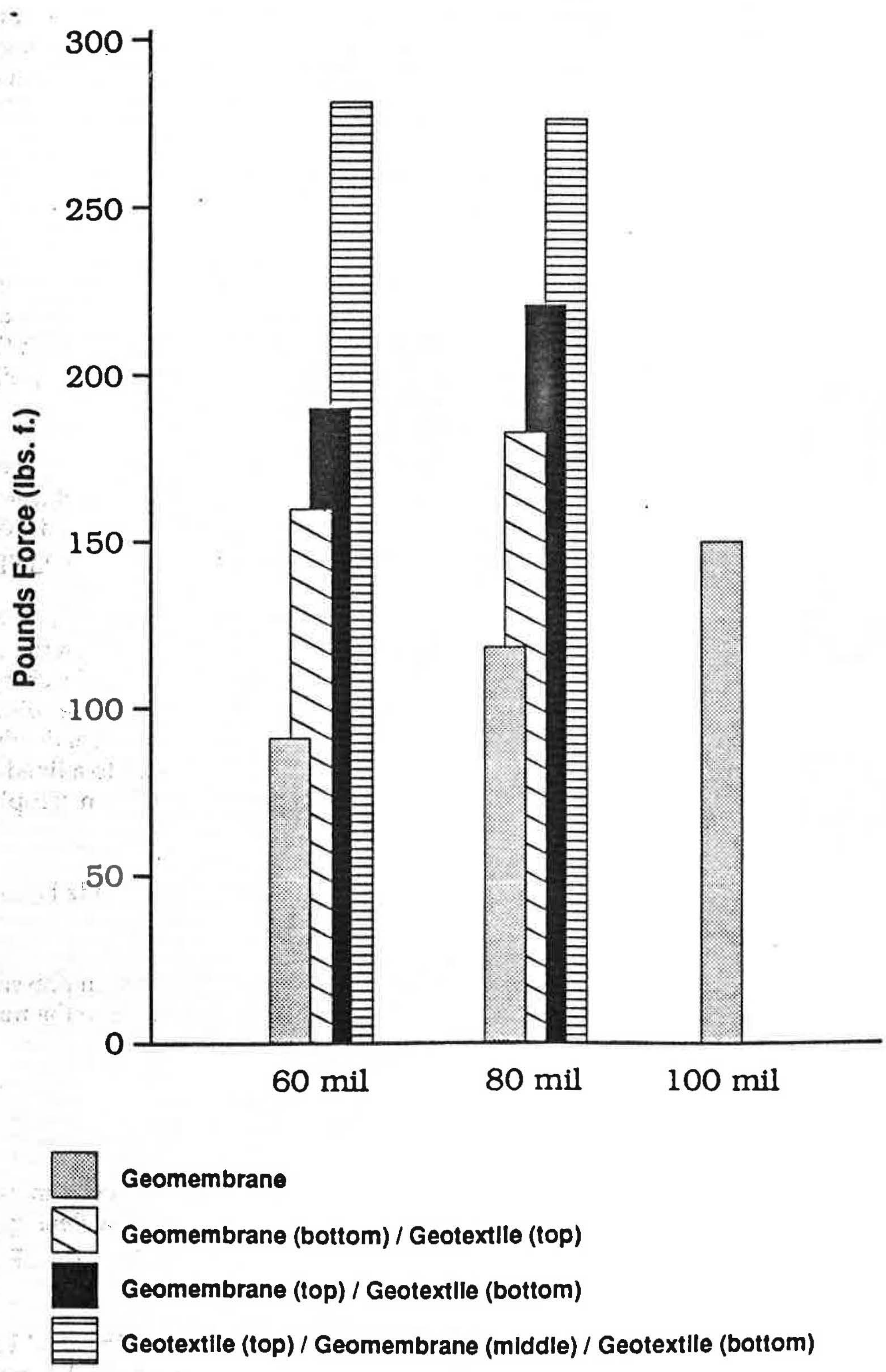
GPO 688-584/19262

Energy Absorbed During Tensile Rupture: Smooth HDPE (Poly-Flex), PVC, and VLDPE (Dura-Flex)



Puncture Resistance Results
Geomembrane and Geotextile Composites

Test Method: FTM 101C 2065



Geomembrane: Typical 60, 80, and 100 mil Poly-Flex

Geotextile: 12 oz./sq. yd. Nonwoven, Needlepunched, Polyester

GEOMEMBRANE USES IN THE MINING INDUSTRY

JOHN D. VANDERVOORT

ABSTRACT

Over the years geomembranes of many types have been used in the mining industry. Because of greater concerns for the environment, the use of geomembranes has grown considerably. This paper discusses the use of synthetic materials as heap leach pads, pregnant pond liners, and barren pond liners. Information is presented on materials, design, selection, failure modes, and quality.

HISTORY

Synthetic materials first came into use in the 1940's for barrier applications and since then has grown in volume and applications as concerns for protecting the environment have increased. The four most common synthetic materials used in mining applications in the past have been chlorinated polyethylene (CPE), chlorosulfonated polyethylene (CSPE), high density polyethylene (HDPE), and polyvinyl chloride (PVC).

As time passed the use of heap leaching became an economical process for processing oxidized ores with very low grades. Because of the economies of this method of leaching low grade ores, the use of geomembranes has increased greatly. In 1988 it is estimated that over 100,000,000 square feet was used in the United States for gold and copper leaching operations.

Using gold as an example; a typical leaching operation involves the sprinkling of a weak sodium cyanide solution over the crushed ore. This solution percolates through the ore to the geomembrane (liner). The geomembrane prevents the loss of gold, the loss of leaching solution, as well as reducing and/or eliminating the contamination of the soil below. The solution goes to a pregnant pond which is also lined with a geomembrane. The pregnant pond solution is then processed to extract the gold whereupon the resultant solution is sent to a lined barren pond. The solution here is then adjusted and returned to the sprinkler system completing the cycle.

Depending upon the particular mine circumstances the design can include heaps in excess of 300 feet high.

Because of several factors, but mainly cost, CPE and CSPE are not seen in present day heap leach operations. The predominant materials now being used as liners in the mining area are polyethylenes and polyvinyl chlorides.

MATERIALS

As mentioned above, in 1988 HDPE and PVC were the predominant geomembrane materials being used in mining applications. Another material known as very low density polyethylene (VLDPE) entered this area of mining use in 1988. A brief description of these products follow:

HDPE - A polymer produced by the polymerization of ethylene. Typical HDPEs used as geomembranes have a natural density of 0.935-0.940 g/cc. Polyethylene materials must contain 2-3% carbon black in order to give the material good ultra violet (UV) protection from sunlight. Geomembranes made of HDPE are manufactured by either sheet extrusion or blown film extrusion. Widths of the final sheet product are normally in excess of 20 feet.

PVC - A polymer produced by the polymerization of vinyl chloride monomer. PVC materials contain plasticizers in order to make the polymer flexible. PVC geomembranes are typically produced by a calendering process. Because this process makes film and sheet in narrower widths, the field geomembranes commonly go through a factory seaming process so final delivered product is wider so as to reduce field seaming.

VLDPE - As with HDPE, this polymer is also produced by the polymerization of ethylene. It's natural density, however, is in the range of 0.890-0.900 g/cc which accounts for its greater flexibility. VLDPE also requires carbon black for UV resistance.

Typical physical properties of the above materials would be:

PROPERTY	TEST METHOD	UNITS	HDPE	PVC	VLDPE
Thickness	ASTM D1693	mil	30	30	30
Density	ASTM D1505	g/cc	0.94	1.250	0.90
Tensile @ Break	ASTM D638	psi	4200	3100	4100
Elongation @ Break	ASTM D638	%	800	300	1200
Tear Strength	ASTM D1004	lbs	23	12	14
Low Temp. Brit.	ASTM D746	C	-94	-30	-94
Dimensional Stab.	ASTM D1204	%	1	5	1

PVC has been used in mining applications since the 1950's whereas HDPE was first used in this area in 1980. The main advantages of HDPE were greater strength, chemical resistance, cold temperature properties, and UV resistance. PVC had the advantage of experience in the industry and greater flexibilty. Until 1987 PVC was generally considered to be less expensive in the same mil thickness but this is no longer the case when all aspects of the liner cost are accounted for.

Because of the desire for the improved properties of the HDPE and the flexibility of the PVC it was desirable to develop a more flexible polyethylene. Thus VLDPE was initially developed as a geomembrane for applications requiring more flexibilty such as canals, caps, and fish hatcheries. It became a natural for mining heap leaching operations because of these properties and was successfully introduced into mining applications in 1988. Toughness comparisons are shown for HDPE, PVC, and VLDPE on the attached stress/strain curves.

DESIGN AND MATERIAL SELECTION

The typical heap leach design contains a single geomembrane. This is also true of the pond designs although there are cases where a double liner has been used for ponds. Whenever usin PVC the pad must have a smooth foundation and because of a lack of UV protection the PVC must always be covered. HDPE generally specifies that the ground not contain any sharp objects greater than 3/8 inch in diameter. Because of extensive hydrostatic and other testing there have been cases where VLDPE has allowed the dirt specification to be increased to objects up to 1 1/2 inches in diameter. Both HDPE and VLDPE can be left exposed to sunlight when properly formulated.

SHIPPING AND USE SAFETY

- HOW IT IS SHIPPED AND USED
  - CONTAINER
  - TRUCKER
  - TRAINING
  - EMERGENCY PLANNING
  - DU PONT "CYANIDE EMERGENCY HOTLINE" PHONE

- PERSONAL SAFETY EQUIPMENT
  - CHEMICAL SPLASH GOGGLES
  - NEOPRENE GLOVES
  - RESPIRATORS:
    TOXIC DUST AND MIST
    CYANIDE GAS
  - RUBBER FOOTWEAR, APRONS, SUITS
  - CLOTHING CHANGE PROCEDURES

- CYANIDE GAS DETECTION
  - ODOR/TASTE/SENSATION
  - DETECTORS: PORTABLE AND STATIONARY

- HOW TO HANDLE A SPILL

SODIUM CYANIDE FACTS

- U. S. USE - 100 MILLION LBS/YEAR.
- USED IN MINING OVER 100 YEARS.
- NO KNOWN DEATHS IN U.S. MINING INDUSTRY WITH DU PONT CYANIDE _ _ _ EVER.
- NO DEATHS OR SERIOUS ENVIRONMENTAL PROBLEMS FROM SHIPPING.
- NOT A PERMANENT POLLUTANT.
  - CAN BE DESTROYED CHEMICALLY
  - WILL BE DESTROYED IN NATURE
  - SMALL AMOUNTS ARE NOT TOXIC
- TECHNOLOGY EXISTS TO OPERATE AND CLOSE MINES SAFELY.

SODIUM CYANIDE

- CONCEPTS: "HAZARD" VS. "TOXICITY"

  - DRY SODIUM CYANIDE
  - WET SODIUM CYANIDE AND SOLUTIONS
  - HYDROGEN CYANIDE (HCN), CYANIDE GAS

- TOXICITY

  - HIGHLY TOXIC
  - FAST ACTING
  - NON-CUMMULATIVE
  - DOES NOT CAUSE CANCER
  - MINIMAL LONG TERM HEALTH EFFECTS
  - EFFECTIVE ANTIDOTE AVAILABLE

CYANIDE POISONING

- HOW CYANIDE ENTERS THE BODY
- EFFECTS OF CYANIDE IN THE BODY
- TREATMENT
  - FIRST AID: AMYL NITRITE AND OXYGEN
  - MEDICAL TREATMENT: QUALIFIED MEDICAL PERSON
INTRAVENOUS INJECTIONS
- TIME FRAME FOR:
  - CYANIDE INHALATION
  - SKIN ABSORPTION
  - SYMPTOMS OF POISONING
  - FIRST AID RESPONSE
  - OVER-REACTION